ELECTRICAL TRACTION

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IN TWO VOLUMES

VOL. I.
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PREFACE.

SINCE the first edition of *Electrical Traction* was published in 1897, progress in this branch of electrical engineering has been extremely rapid, though not perhaps such as to satisfy its most ardent advocates. This advance has been so great that it has been found necessary, in preparing a second edition, practically to rewrite the entire book; in so doing, the extent of the ground to be covered has, in the authors' opinion, justified a considerable enlargement of the original volume.

The present book has been arranged in two parts, the first of which deals with the application of direct current electricity to traction both for tramways and for railways, and the second of which is devoted to the similar application of alternating currents. Although this forms a natural division of the subject, the installations in which direct current is employed are so much more numerous than those using alternating currents that the division is somewhat unequal. The authors have, however, preferred to adhere to this plan, rather than arrange the matter in a single volume or in two equal volumes, in the belief that in this way each volume, being practically self-contained and complete in itself, will be more acceptable to the engineering public.

In dealing with the various systems of electrical traction the authors have avoided, as far as possible, any direct advocacy of one rather than another; but have endeavoured to point out impartially the advantages and disadvantages inherent in each system. There are comparatively few engineers in a position to make a decision of such importance, and since any such decision should be based upon the consideration of all the various aspects of the case, the authors have made it their aim to present all the available information as to the apparatus obtainable, its design, efficiency and reliability, in such a way as to facilitate the work of responsible engineers.

The authors are fully conscious that the book is incomplete in many respects, and that any practical engineer who has specialised in one particular branch of electrical traction will be able to point out gaps and possibly inaccuracies in the chapters dealing with that branch. Few people, however, have a special knowledge of the whole range of traction, and it is hoped that those who have specialised may find some fresh information in those branches with which they are not so familiar. For advanced students, also, who may intend to take up this subject, the first volume, and later perhaps the second volume, may be found useful.

A word of explanation may be necessary with regard to the treatment of motor design. A great deal has been published in the past as to direct current motors, and to repeat it in this book would be to travel somewhat beyond the natural limits of the subject. The case is quite different for alternate current motors for traction purposes both polyphase and single phase, and in consequence considerable space has been devoted in the second volume to this matter, as information thereon is not readily obtainable.

In acknowledging assistance from various quarters it is necessary to mention first of all those manufacturing firms who have placed information at the disposal of the authors; of such firms Messrs Siemens-Schuckert, of Berlin, and Messrs Siemens Brothers, of London, have supplied much unpublished material and a number of original drawings, for which the authors wish to tender their thanks. Other firms have given much assistance, viz., the British Thomson-Houston Co., and the General Electric Co. of America, the British Westinghouse Co., Messrs Dick Kerr and Co., Messrs Ganz and Co., the Oerlikon Elektricitäts Gesellschaft, and the Algemeine Elektricitäts Gesellschaft.

In many cases items of information have been drawn from the technical press, acknowledgments for which have generally been made in the text; the chief source of such information has been the *Street Railway Journal*, and others are *Traction and Transmission, The Electrician*, and the *Electrical Review*. To these journals the authors wish to express their indebtedness.

The individuals to whom the authors are under an obligation are numerous. Mr A. P. Trotter, the electrical adviser to the Board of Trade, has given much information; Mr T. H. Schoepf, formerly of the British Westinghouse Co., Mr T. Stevens of the British Thomson-Houston Co., and Mr P. R. Brown of Messrs Hadfield's Steel Foundry Co., have

been of assistance in many ways ; Herr A. Schmit of Messrs Siemens-Schuckert, has supplied a good deal of information with regard to Continental practice, and Mr Mittelhausen of the Bexley Heath Tramways, has put at the disposal of the authors his experience in the practical working of electric tramways. Other gentlemen who have kindly helped in various ways are Mr Dalziel, the electrical engineer of the Midland Railway, Mr Roger Smith, the electrical engineer of the Great Western Railway, Mr Huddleston of Messrs Siemens Brothers and Co., in connection with cables, and Mr A. C. Kelly of the British Westinghouse Co. Acknowledgments are due in a special way to Mr C. F. Jenkin of Messrs Siemens Brothers Dynamo Works.

In reading the manuscript and correcting the proofs the authors have received much valuable assistance from Mr R. E. Shawcross, Mr A. E. and Mr G. F. Odell, and in preparing the diagrams from Mr F. C. Summerson and Mr E. P. Hardy.

To all these gentlemen the authors tender their heartiest thanks.

ERNEST WILSON.
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CHAPTER 1.

INTRODUCTION.

Ever since the first discovery that a dynamo electric machine was reversible and conld be used to transform electrical into mechanical energy, the application of electricity as a means for propelling vehicles must have been present in the minds of engineers. This branch of electrical engineering has, however, been eclipsed up to the present time by other branches, chiefly the production and supply of electricity for illumination. The eclipse, however, is not in any way total, being purely quantitative. Many traction systems are in operation, and are in every way fully developed, and it is only in comparison by means of statistics that any inferiority is manifest. In fact, it seems clear that, as far as the design of suitable apparatus is concerned, electric traction may claim a definite superiority. It utilises the experience and the plant that have been evolved in the other branches, and adds thereto a large range of special apparatus and a considerable volume of experience which are not essential to electrical engineering in general. This may be illustrated by the contents of this book. It has been the authors' aim to treat only of this special apparatus which is peculiar to electric traction, leaving apart the accessories which are incidental to such work and which are shared by other branches of engineering. It will be obvious, therefore, that electric traction, while making full use of the fundamental apparatus of other branches, has erected for itself a superstructure of its own which is the result probably of more creative genius than can be claimed by any of its rivals.

The following figures, which have been compiled from the supplement to the *Electrician* for January 4th, 1907, shew very clearly the relative extent of electric supply undertakings and traction undertakings.

Total capacity of generating plant installed in the stations of electricity supply undertakings with no tramway load	about	410,400 kw.
Total capacity of generating plant installed in the stations of electricity works supplying both lighting and tramways	about	346,100 kw.

[For these electricity works the total connections excluding traction amount to about 339,000 kw. and the maximum traction load to about 100,000 kw.]

Total capacity of generating plant installed in the stations for tramways and light railways only, about 69,300 kw.

Total capacity of generating plant installed in the stations for electric railways* about 89,800 kw.

The whole subject may be divided into two convenient classes, that in which the traction apparatus utilises direct currents and that in which alternating currents are employed. In many ways, chronological and otherwise, the first class is the most important; it is very much more extensive in operation and it contains apparatus which has been brought to a high pitch of perfection. The second branch, on the other hand, may be said to be in its infancy; but it contains so much promise of growth that to many engineers it may seem to hold out more inducements for devoting time and energy to its study. Without doubt there is much fascination in connection with a new science which is in the first stages of its evolution; but in this case it is certainly not advisable to pass over the earlier work in connection with direct currents, as the only sound proceeding is to assimilate and incorporate into the new departure as much as possible of the experience gained in the past. A comparison of the apparatus required for direct current traction work with that used with alternating currents will shew that those who have been responsible for the development of the engineering details in the latter have followed very closely the methods employed in the former, introducing only such modifications as are essential or are justified by the difference of system.

A chronological survey of electric traction would undoubtedly possess great interest, and much might be learnt from it. It would, however, if thoroughly made, occupy a good deal of space and no attempt at such a survey has been made in the present case. The authors have nevertheless adopted an arrangement in which in a broad way chronological order has been adhered to. In carrying out this purpose direct current traction takes the first place and in this division electric tramways are treated first and then direct current electric railways. Following this a section is devoted to the application of three-phase alternating currents to electric railway problems, and finally the latest developments in single phase alternating current traction are discussed at considerable length.

There is no need at this period of development to urge the advan-

* Electric power for working the electrified lines of the North Eastern Railway is obtained from the Newcastle Electric Supply Company, and is therefore not included in this item.

tages of the application of electrical working to tramways. These advantages are so widely recognised that practically every town of importance in the United Kingdom possesses its own system, and it is chiefly for this reason that the rate of growth in this direction is not greater. London formed the main exception to this state of affairs until quite recently; but within the last few years the London County Council have taken in hand electrification on a large scale. The figures already given in relation to the capacity of the generating plant installed shew that a great deal has already been done, but these figures may be supplemented from the Board of Trade Return* in connection with Tramways and Light Railways for the year 1905–6.

In 1905–6 the total route mileage of Tramways and Light Railways in the United Kingdom was 2240, of which 1994 miles were worked by electric traction. This total mileage was divided among 312 distinct undertakings of which 175 belonged to local authorities and 137 to other parties. The following table gives an interesting comparison between four different years, viz. 1879, when the tramways were mainly worked by horse-power; 1898, when the use of steam power was at its maximum, and 1904–5 and 1905–6 when electric working predominated.

	1905–6	1904–5	1898	1879
	Electric period		Steam period	Horse period
Length of route open—miles	2,239·99	2,116·78	1,064·19	321·27
Total number of passengers carried	2,236,012,777	2,068,913,226	858,485,542	150,881,515
Capital expenditure per mile of single track open—lines and works	£12,122	£11,799	£7,770	£7,840
All items	£16,195	£15,599	£10,469	£9,877
Percentage of net receipts to total capital outlay	6·54	6·36	6·38	3·97
Do. to net capital outlay (eliminating amounts expended on construction or purchase of old lines and works now superseded)	7·05	6·80	not available	not available
Percentage of working expenditure to gross receipts	64·23	66·19	76·93	83·81
Passengers carried per mile of route open	998,226	977,386	806,703	469,641
Passengers carried per car mile......	9·16	9·10	9·48	7·77
Average fare per passenger...........	1·10*d.*	1·10*d.*	1·23*d.*	1·84*d.*
Amount paid in relief of rates out of profits of undertakings worked by local authorities	£205,981	£209,881	not given	not applicable

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From these figures it will be apparent that the advantages and applicability of electric working to tramways and light railways are clearly understood. The case of railways is quite different, and it may be said that the arguments in favour of electrification are not so obvious. No really conclusive reasons for a wholesale change from steam to electricity for railway working have yet been put forward, although in the opinion of many engineers such a change is inevitable rather as a result of a gradual process of expansion than owing to any sudden decision on the part of the various railway companies.

The various aspects of railway electrification are dealt with in the following pages mainly from the standpoint of the engineer, but briefly also from the financial point of view. Apart, however, from the question of general electrification, electrical working has a field of its own in which it has no rival. For railways which work altogether or mainly in tunnels the disadvantages inherent in the use of the steam locomotive are so great that as soon as suitable electric apparatus was developed its adoption was practically inevitable. Especially has this been the case in the deep level tunnels or "tubes" in London, in which steam locomotives are quite out of the question.

Of the 310 miles of single track worked partly or solely by electricity at the end of 1905 in the United Kingdom 34 are in deep level tunnels in London, 120 are owned by or connected with the Metropolitan and Metropolitan District Railways of London, and 110 by the North Eastern Railway and the Lancashire and Yorkshire Railway.

In the United States of America and on the Continent of Europe electrification of railways is in general in much the same condition. The development of deep level railways has not progressed to the same extent as in London, but instead there are in the United States and in Germany overhead railways several of which are already equipped for electrical working, while schemes are constantly being discussed for the conversion of others. There are also in Switzerland many mountain railways to which electricity has been applied.

The evolution and introduction of alternate current working have been most conspicuous in the North of Italy, where the three-phase system has been applied to the working of a portion of the State Railways. This system has been in operation for some four or five years with uniform success. For various reasons, however, the three-phase system has not been so widely adopted as might have been expected, and, in consequence, great hopes have been entertained of the single phase system of alternating current traction which has been brought out quite recently and from many points of view seems to combine the advantages of the three-phase and the direct current systems.

Although single phase traction has been a practical possibility only within the last three or four years it has made so much progress that already several railways have been equipped in the United States and on the Continent, and in this country two contracts are being carried out, on the Suburban lines of the London Brighton and South Coast Railway and on a short length of the Midland Railway in the neighbourhood of Lancaster.

It will be apparent, therefore, that, although the present utilisation of electricity on railways is not very great in comparison with the enormous volume of steam working, there is even now sufficient to be of great interest to the electrical engineer, and there appears a high probability of future extension on a scale that will put electric traction far ahead of all its rivals.

CHAPTER 2.

THE DIRECT CURRENT TRAMWAY MOTOR.

Of all the apparatus that composes the equipment of an electric tramcar, the motor is undoubtedly the most essential item. It is the direct agent whereby electrical energy is converted into the mechanical energy necessary for propelling the car. All the other items are simply auxiliaries in comparison with the motor, and therefore must occupy a second place in the study of the equipment.

Requirements. Dealing first with the requirements of the modern tramcar in the way of motive power, some preliminary ideas can be obtained by consideration of the weights of the cars and chiefly the accelerations necessary to enable the cars to maintain the desired schedule.

As an example, suppose the weight of a car, equipped and fully loaded, is 10 tons, and that it is necessary to start with an acceleration of 2·0 ft. per second per second, and further that the tractive resistance amounts to 20 lbs. per ton; then the tractive force at the periphery of the driving wheels must be

$$\frac{2}{32 \cdot 2} \times 10 \times 2240 + 20 \times 10 = 1590 \text{ lbs.}$$

[or thus: reckoning 70 lbs. per ton as the necessary tractive force to produce 1·0 ft. per second per second acceleration

$$\text{tractive force} = 10\,(2 \times 70 + 20) = 1600.]$$

In practice it is usual to put two motors on a car, although occasionally four motors are used.

With two motors, the tractive force per motor will be 800 lbs. On the assumption that this acceleration is maintained until a speed of 10 miles an hour is reached, the maximum output of each motor will be

$$\frac{800 \times 10 \times 1 \cdot 466}{550} = 21 \cdot 3 \text{ brake horse-power.}$$

There are, however, in practice, many considerations which govern the choice of a motor to suit any given set of conditions, such as the gradients, the probability of using trailer cars, the frequency of stopping and starting, and so on.

As the result of experience manufacturing firms have worked out four or five standard sizes such as 25, 30, 35, 40 and 45 horse-power reckoned on the basis of the 1 hour test*. It is unlikely that any motor outside this range would be necessary for an ordinary tramway system.

Choice of motor. It is, of course, possible, if complete data are obtainable, to calculate the necessary output of the motor. For instance, the conditions might be, and, in fact, have been, put in the form that a tramcar of a certain total weight is to be driven over a certain course at a certain average speed with so many stops of a known duration, and that this test is to be continued for 12 hours, and further that at the end of the test the temperature rise of any part of the motor shall not exceed 75° C. Given such a specification, it is quite possible to calculate the size of motor required; but an engineer issuing such a specification takes the responsibility of asserting that it is sufficient and that more severe conditions will not arise in practice.

It is more usual to decide upon the motor arbitrarily, and considerable experience is required to enable a satisfactory choice to be made.

The case of railways. In the choice of motor for an electric railway, the conditions to be met are much more precise, and calculations must be made. The method of calculation is described later on.

Design of the tramway motor. General. It is impracticable in a book such as this to devote very much space to the design of the tramway motor. Much has already been published on the design of motors in general, and of tramway motors in particular; and it is proposed here only to bring out those points in which the traction motor is peculiar, and, for the sake of illustration, to work through the calculations for a 35 H.P. motor manufactured by Messrs Dick Kerr and Co.

Distinguishing features. It may be said that the distinguishing features of the traction motor are four in number:

(1) the motor is series wound,
(2) it is totally enclosed,
(3) it is suspended in a way peculiar to itself,
(4) its direction of rotation must be reversible without any adjustment of the brushes.

The first point is purely electrical; the second is both electrical and mechanical, in that it affects both the electrical design, because of the

* "The commercial rating of a railway motor should be the H.P. output giving 75° C. rise of temperature above a room temperature of 25° C. after one hour's continuous run at 500 volts terminal pressure on a stand with the motor covers removed." Report of Committee on Standardisation, June 20, 1902. *Transactions of American Institute of Electrical Engineers*, vol. 19, p. 1083.

heating of the motor, and also the construction; the third point is entirely mechanical; and the fourth electrical.

The last point is perhaps the most interesting to the electrical engineer. Practically speaking, the successful working of the traction motor has been made possible by the use of carbon brushes, which with a suitable design will effect commutation when fixed permanently in the neutral position.

It is also essential for satisfactory working that the number of commutator parts should be large; and further that the ratio of the ampere turns per pole on the field to the ampere turns per pole on the armature should be kept high, in fact, not much less than 2. This latter condition ensures minimum distortion of the field, without which sparkless commutation in the neutral position would be impossible.

Without going through the theory of the design of a motor, which can with advantage be studied elsewhere, it will be advisable to consider the calculation of the performance curves, and a few points in connection therewith.

A sheet of performance curves of a traction motor generally includes the curves of speed, brake horse-power, efficiency, and tractive effort, plotted against current, and also a curve shewing the time for which any given current can be passed through the motor without the temperature rise exceeding 75° C. There are thus 5 curves with current as abscissa, and this method is generally adopted in this country and in the United States. On the Continent, however, it is usual to plot the curves against tractive effort as abscissa.

The curves of speed, brake horse-power, efficiency and tractive effort can be calculated at once when the motor is designed and all the losses obtained for different values of the current. The method of obtaining the heating curve, however, is not so obvious, and it may be advisable to refer briefly to this before working out an actual example.

The time-temperature curve. Consider the losses in the motor; they may be enumerated as follows:

1. C^2R in the field winding.
2. C^2R in the armature winding.
3. Iron-loss in the armature core and teeth.
4. C^2R on the commutator.
5. Brush friction.
6. Bearing friction and windage.

In addition to the above there is the loss in the gearing; but, although this loss influences the efficiency curve, it hardly affects the heating of the motor.

Beginning at the lower end of the time-temperature curve, it will be obvious on consideration that most of the loss occurring in the motor

goes toward heating up the iron and copper, and, the time being so short, very little heat is radiated away. Following the method described by Goldschmidt*, the average watts that can be absorbed by the field coils while the current is flowing can be calculated as follows:

Let M be the mass of the field coils in lbs. Then the heat capacity will be Mk where k is the specific heat of copper. Allow an increase of 30 per cent. to include the heat capacity of the insulation, and multiply by 1880 to obtain the watt seconds required to heat the coils 1° C. To heat them 75° C. in t minutes the average watts will be

$$Mk \times 1{\cdot}30 \times 1880 \times \frac{75}{60t},$$

and knowing the average resistance, the corresponding current is at once calculated.

Thus taking $k = {\cdot}09$, the average watts will be $M \times \dfrac{275}{t}$;

or if R be the resistance $C = \sqrt{\dfrac{M \,.\, 275}{R \,.\, t}}$.

Precisely the same method can be adopted for the armature, although in this case the calculation is bound to be more approximate. In this case the copper is not in a mass, but is distributed over the armature surface, and is in intimate contact with the core plates. It is reasonable to assume, therefore, that the whole mass of the armature partakes in the absorption of heat, and for short runs a fairly good result is obtained by assuming that the armature as a whole, including winding, core plates, spider, shaft and commutator, has an effective specific heat of ·1, and that the average temperature rise of the whole mass is $\frac{3}{4}$ of the maximum temperature rise. Then if M_1 be the total mass of the armature in lbs.,

$$M_1 \times {\cdot}1 \times 1880 \times \frac{\frac{3}{4} \times 75}{60t} = \frac{176\,M_1}{t}$$

will be the average loss in the armature during t minutes, and includes C^2R, iron and friction losses. From a curve of losses plotted against current the value of the current can be determined.

For periods of half an hour and 1 hour, some account must be taken of the heat radiated as well as that absorbed. From the nature of the case any formulæ which may be proposed can only give approximate results when applied to a wide range of traction motors. Fairly good results, however, can be obtained for the heating of the armature by assuming the same heat absorption as above, and allowing a heat radiation of about 1·8 watts per square inch of the surface of the armature and commutator.

Thus the total watt-seconds in t minutes will be

$$M_1 \times {\cdot}1 \times 1880 \times \tfrac{3}{4} \times 75 + A \times 1{\cdot}8 \times 60t$$

* *Proc. Inst. Elec. Eng.*, March 9, 1905.

where A is the surface of the armature and commutator in square inches, and the average watts will be

$$\frac{M_1 \times 176}{t} + A \times 1\ S.$$

The heating of the field coils for short periods may be treated in the same way. In this case, for half an hour or for one hour, the heat radiated is small compared with the heat absorbed, and consequently uncertainty as to the allowance for radiation will not greatly affect the accuracy of the prediction.

A reasonable figure to assume for 75° C. rise, as measured by thermometer, may be taken as 0·2 watt per square inch, the surface being reckoned as the perimeter of the cross-section of the coil multiplied by the length of the mean turn.

For continuous or intermittent running it is best to regard only the C^2R watts in the armature. An allowance of say 0·4 watt per square inch of surface of the armature winding gives fairly good results for 75° C. rise; and the same figure for radiation from the field coils as mentioned above.

These figures are, naturally, somewhat rough, and it is obvious that different types of motor will vary considerably in their heating constants. It is, of course, more satisfactory to obtain the time-temperature curve by direct testing; but it frequently happens that this cannot be done before the performance curves are drawn up. The above method may, therefore, be of use in such cases.

Specification No. 1.

Direct Current Tramway Motor.

35 H.P. 500 volts. 480 r.p.m. 75° C. rise after 1 hour.

Armature.

External diameter	$14\frac{1}{2}''$	Opening of slot	·56″
Internal diameter	6·2″	Type of winding	2 circuit
Gross length	8″	Number of poles	4
Air ducts	$2-\frac{1}{2}''$	Conductors per slot	24
Nett length	7″	Scheme of connections*	1 \ 50 / 125
Percentage iron	say 90 °/。		
Length of iron	6·3″		
Number of slots	41	Size of conductors	·0106 sq. ins.
Width per slot	·56″	Resistance (hot)	·43 ohm
Depth per slot	1·4″	Weight of copper	72 lbs.

* This scheme of connections is worked out on the basis of numbering the conductors in the slots as follows:

Slot 1	Slot 2
1 3 5	7 9 11
2 4 6	8 10 12 &c.;

where each number represents a group of four wires in series.

Commutator.

Diameter	11″	Number of segments	123
Length	$4\frac{3}{4}$″	Thickness of mica	$\frac{1}{32}$″

Brushes.

Number of brush arms	2	Section of each brush	$1\frac{3}{8}'' \times \frac{1}{2}''$
Brushes per arm	2	Quality of carbon	"ordinary"

Field.

Pole pieces laminated		Section of yoke (approx.)	12 sq.″
Number of poles	4	Turns per coil	125
Bore	15″	Section of copper	·0423 sq. in.
Dimensions of pole face	8″ × 8″	Resistance (hot)	·37 ohm
Dimensions of pole core	$5\frac{1}{2}'' \times 7''$	Weight of copper	256 lbs.

Data for calculating performance Curves.

1. **Saturation curve.** The method of calculation of the saturation curve is well known and need not be repeated here. It will be sufficient for present purposes to assume that this curve is known, being as shewn in figure 1.

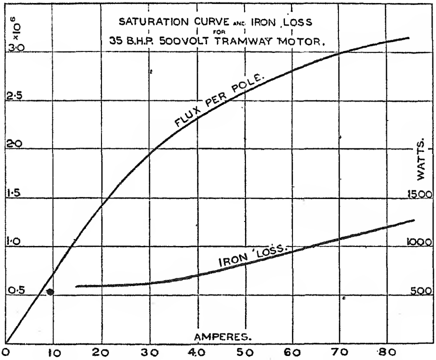


Fig. 1.

2. **Brush resistance.** The contact resistance of carbon brushes is not a constant quantity, but varies with the current density. The simplest way of expressing this variation is by the formula

$$\text{voltage drop} = A + B \times \text{current},$$

where A and B are constants.

For "ordinary" quality of carbon brush approximate values are $A = \cdot 65$ and $B = \cdot 013$ per sq. inch.

3. **Internal drop.**

Armature resistance (hot)	·43 ohm
Field coils resistance (hot)	·37 ohm
Resistance of brushes (constant B only) $2 \times \dfrac{\cdot 013}{2 \times 1\frac{3}{8} \times \frac{1}{2}}$ ...	·019 ohm
Total say	**·82 ohm**

$$\therefore \text{ drop} = (\text{current} \times \cdot 82) + 2 \times \cdot 65$$
$$= C \times \cdot 82 + 1 \cdot 3.$$

4. **Speed.** E.M.F. generated by rotation in the magnetic field
= flux per pole × revolutions per second × number of poles × number of conductors in series between brushes × 10^{-8}

$$= \frac{F \times \text{r.p.m.} \times 4}{60} \times \frac{41 \times 24}{2} \times 10^{-8}.$$

$$\therefore \text{ r.p.m.} = \frac{\text{back E.M.F.}}{\text{flux per pole} \times 10^{-6}} \times 3 \cdot 05.$$

5. **Losses.**

(*a*) C^2R or current multiplied by drop.

(*b*) Iron loss.

This loss is very difficult to estimate accurately. The watts lost due to hysteresis and eddy currents in the armature core plates, as calculated by means of the usual constants, are not sufficient to account for the total iron loss observed experimentally. There is evidently some additional loss which must be included. Various attempts have been made to find a formula which will give satisfactory results, and one of the latest* is based upon the supposition that the extra loss occurs in the iron end plates which clamp together the armature laminations.

The formula for the extra loss is

$$1 \cdot 15\, d \left(\frac{\text{A.T.} \times f}{s}\right)^2 \times 10^{-8} \text{ watts,}$$

where d is the diameter in inches of either end plate,

A.T. the ampere turns per pole required to magnetise the air gap and the teeth,

f the frequency $= \dfrac{\text{r.p.m.} \times \text{no. of poles}}{120}$,

and s the depth of the slot in inches.

This formula applied to the present case gives fairly satisfactory results, and the total iron loss is shewn in figure 1.

* *Electrical Review*, July 7, 1905, p. 4.

(*c*) Brush friction.

This loss is assumed to be proportional to the speed. Making an allowance of 25 oz. per square inch pressure between the brushes and the commutator, and a coefficient of friction of ·3, the loss at 100 r.p.m. will be

$$0{\cdot}3 \times 100 \times \frac{\pi \times 11}{12} \times \frac{25}{16} \times 4 \times 1\tfrac{3}{8} \times \tfrac{1}{2} \times \frac{1}{33000} \times 746 = 8{\cdot}4 \text{ watts.}$$

(*d*) Bearing friction and windage.

Assume 40 watts at 100 r.p.m., the loss varying as the 1·5th power of the speed; i.e.

$$\text{loss} = 40 \times \left(\frac{\text{r.p.m.}}{100}\right)^{1\cdot5} \text{ watts.}$$

Calculation of performance curves.

500 volts.

Current	15	25	35	45	55	65	75	85
Flux per pole in 10^6	1·1	1·7	2·13	2·45	2·7	2·9	3·05	3·14
Drop (CR + 1·3)	13·6	21·8	30	38·2	46·4	54·7	62·8	71
Back E.M.F.	486·4	478·2	470	461·8	453·6	445·3	437·2	429
Speed r.p.m.	1350	855	670	572	510	466	437	415
Losses								
Current × drop	204	545	1050	1720	2550	3560	4710	6000
Iron loss	600	620	660	770	880	1020	1130	1260
Brush friction	113	72	56	48	43	39	37	35
Bearing friction and windage	2000	1000	700	550	460	410	365	350
Total	2920	2240	2470	3090	3930	5030	6240	7650
Input kw.	7·5	12·5	17·5	22·5	27·5	32·5	37·5	42·5
Output kw.	4·58	10·26	15·03	19·41	23·57	27·47	31·26	34·85
B.H.P.	6·13	13·7	20·1	26	31·5	36·8	41·8	46·7
Efficiency °/o	61	82	86	86·5	85·6	84·5	83·5	82
Torque (lbs. at 1 ft. radius)	23·4	84	158	239	325	415	505	590

Time-temperature curve.

A rise of 75° C. **in 10 minutes.**

Weight of 4 field coils = 4 × 64 lbs. = 256 lbs.

Average resistance = ·34 ohm.

$$\therefore\ \text{C} = \sqrt{\frac{256 \times 275}{\cdot34 \times 10}} = \mathbf{144} \textbf{ amperes} \text{ (field coils only).}$$

Weight of armature = 556 lbs.

$$\frac{176\ \text{M}_1}{t} = \frac{176 \times 556}{10} = 9800.$$

This corresponds to about **132 amperes** (armature only).

The lower of these two values must, of course, be taken.

A rise of 75° C. **in ½ hour.**

Total surface of field coils........................ 1824 sq. inches.

Surface of armature windings .... 727 „ „

Total surface of armature and commutator... 950 „ „

Armature.

Average value of watts due to absorption of heat by armature and commutator $\Big\} = \frac{98000}{30} = 3270$

Average value of watts radiated $= 950 \times 1 \cdot 8 \qquad = 1700$

Total 4970

This value of watts corresponds to **88 amps.**

Field.

Average value of watts due to heat absorption

$$= \frac{256 \times 275}{30} = \frac{70500}{30} = 2350$$

Average value of watts due to radiation $= 1824 \times \cdot 2 \qquad = \ 365$

Total 2715

This value corresponds to a current of **89·5 amps.**

Therefore, current for half hour $=$ **88 amps.**

A rise of 75° C. **in 1 hour.**

Proceeding as before:

$$\text{The armature watts are } \frac{98000}{60} + 1700 = 3330.$$

Corresponding to a current of **65 amps.**

$$\text{The field watts are } \frac{70500}{60} + 365 = 1540.$$

Corresponding to a current of **67·2 amps.**

Therefore current for 1 hour $=$ **65 amps.**

A rise of 75° C. **in 2 hours.**

$$\text{The armature watts are } \frac{98000}{120} + 1700 = 2515.$$

Corresponding to a current of **48 amps.**

$$\text{The field watts are } \frac{70500}{120} + 365 = 955.$$

Corresponding to a current of **52·8 amps.**

Therefore current for 2 hours $=$ **48 amps.**

Continuous or *intermittent* running.

Average armature watts $\cdot 4 \times 727$ (C^2R only) $= 290$.

This corresponds to **26 amps.**

Average field watts $= 365$.

This corresponds to **31·5 amps.**

Therefore, R.M.S. current for continuous or intermittent running $=$ **26 amps.**

The performance curves thus calculated are shewn in figure 2.

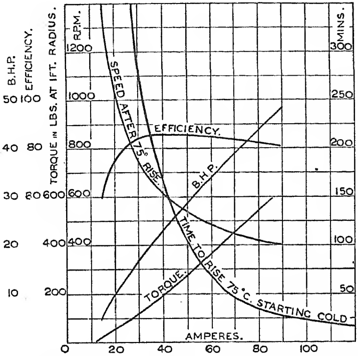


FIG. 2. Performance Curves of 35 B.H.P. Tramway Motor without Gear.

These curves may be called the intrinsic performance curves of this particular motor; when the motor is fitted with reduction gearing and mounted on a car with driving wheels of a given diameter, a fresh

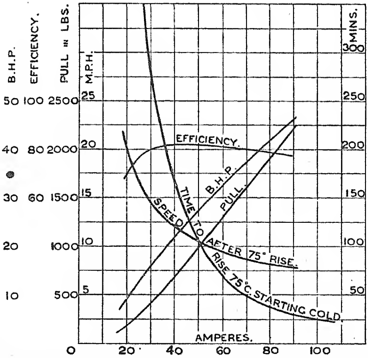


FIG. 3. Performance Curves of 35 B.H.P. Tramway Motor with Gear.

set of curves is generally prepared shewing the speed of the car in miles per hour, the efficiency (including losses in gearing), brake horse-power, the pull at the periphery of the driving wheels, and the time-temperature curve, all against amperes as before.

Figure 3 shews a set of curves for the same motor with a driving wheel 30 inches in diameter, and a gear ratio of 15 to 69.

The process of obtaining these curves from the original motor curves is quite straightforward, the only point to notice being that the efficiency with gearing is less than without. It is usual to assume that the addition of gearing lowers the efficiency 5 per cent. (this of course only applies to machine-cut wheels running in an oil bath). Having thus reconstructed the efficiency curve all the other curves follow directly.

Thus the calculation is made in the following order:

(1) Current in the motor.

(2) Efficiency (including gear).

(3) Miles per hour.

This is deduced from the corresponding motor speed thus:

$$\text{r.p.m.} \times \tfrac{15}{69} \times \text{periphery of driving wheel} = \text{feet per minute,}$$

and therefore $\text{r.p.m.} \times \tfrac{15}{69} \times \pi \times 2{\cdot}5 \times \tfrac{1}{88} = \text{miles per hour}$

$$\textit{i.e.}\ \text{r.p.m.} \times {\cdot}0194 = \text{miles per hour.}$$

(4) Output in B.H.P.

This is obtained from the input in watts, multiplied by the efficiency and divided by 746.

(5) Pull at tread of wheels.

This is deduced from the H.P. and the speed thus

$$\text{pull} = \frac{\text{H.P.} \times 33000}{\text{miles per hour} \times 88} = \frac{\text{H.P.}}{\text{miles per hour}} \times 375 \text{ lbs.}$$

(6) Time-temperature curve, as in the original performance curves.

Curves at 500 *Volts.*

Current	20	30	40	50	60	70	80	90
Efficiency %	70	80	82	82	81	80	78·5	77
Miles per hour	20·2	14·5	12	10·5	9·4	8·75	8·15	7·8
Output, B.H.P.	9·4	16·1	22	27·5	32·6	37·5	42	46·4
Pull in lbs.	186	416	687	985	1300	1610	1930	2230
Time in minutes		275	170	110	70	48	37	30

Construction of the motor. The general details of the construction of the motor are shewn in figures 4 and 5.

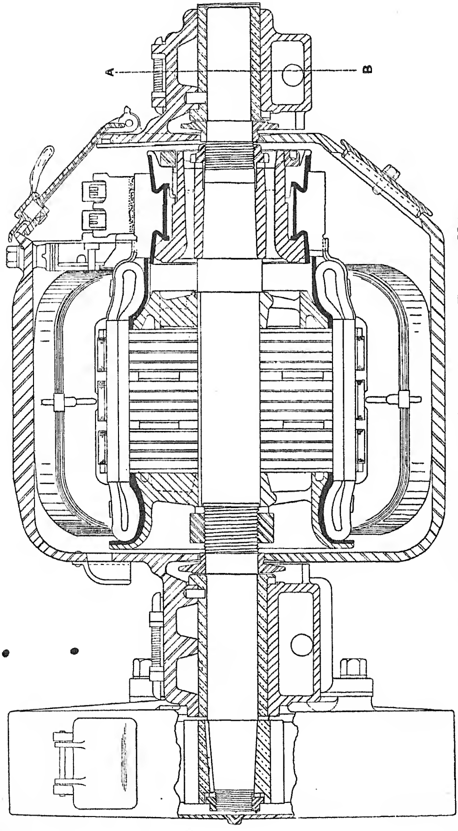


FIG. 4. Longitudinal Section of Dick Kerr 35 B.H.P. Tramway Motor.

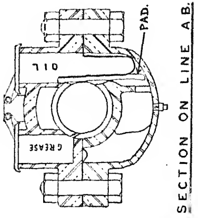


Fig. 6.

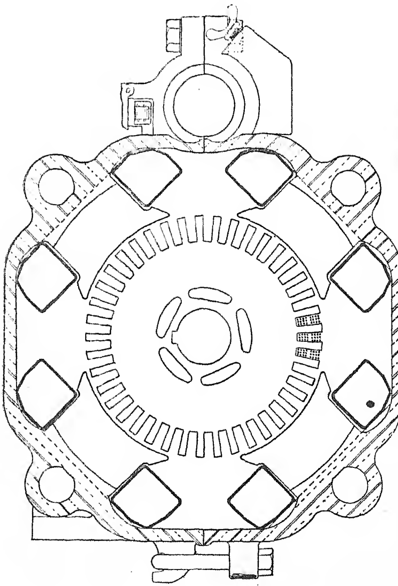


Fig. 5. Transverse Section of Dick Kerr 35 B.H.P. Tramway Motor.

The following description of the motor is extracted from the official specification, and may be taken as typical of modern practice.

The armature. This is of the 4-pole series type and is supplied with two brush-holders. The core is built of soft iron stampings with projecting teeth, between which the coils are bedded, the stampings being coated with insulating varnish. The windings of the armature are former-wound and are thoroughly insulated by composite insulation*, not less than ·04 inch thick including the covering on the individual conductors. Radial apertures are provided through which a current of air is forced when the armature rotates, thereby keeping it cool. The spider arms act after the manner of a fan and keep the air in circulation. The end plates keep the stampings together and are so formed as to support and protect the winding at a uniform distance from the shaft. The coils are formed of round wire having no joints except where they are soldered to the commutator segments. They are securely held in position by wire bands soldered and held by clips. The commutator is constructed of the best hard drawn copper segments insulated from one another by mica, and mounted on a cast-iron ventilated frame. The mica is of such quality that it wears down evenly with the copper and is about $\frac{1}{32}$ inch thick.

The field coils. These are wound with double cotton covered copper wire and asbestos, and soaked after winding with insulating compound. A wrapping of composite insulation at least $\frac{1}{16}$ inch thick is then applied. The exterior of the coils is closely wrapped with linen tape, which is impregnated with paint, thus rendering the coils moisture proof.

The motor frame. This consists of two castings of soft steel with four laminated polar projections. Each of the four poles has its own winding, as this conduces to good performance as regards sparking at the brushes. The poles are provided with air-ducts for ventilation purposes. In order that the armature may be conveniently removed, the frames are so designed that the lower one can be dropped into the car pit or the upper one raised. The bearings are supported entirely outside the frame, and so arranged that the lubricant which runs from them may do so outside the motor. The frame is supplied with doors for convenient inspection of the armature, such doors being ventilated in order to provide a free circulation of air around the commutator and field-coils, but so arranged that water cannot penetrate to the interior unless the motor be actually submerged.

The **pinion** on the motor shaft is of steel, and the **spur-wheel**

* Composite insulation consists of at least two layers of mica together with cloth or fibre insulation treated with insulating and water-proof cement.

with which it is in gear is of cast steel in halves which are bolted together and can therefore be easily placed in position on the driving axle. The teeth are machine cut. The following are the particulars of the gearing:

Gear ratio 4·6 *to* 1.

	Pitch circle Diameter	Diametral pitch	Number of teeth	Width of teeth
Pinion	5″	3	15	$4\frac{5}{8}$″
Spur-wheel	23″	3	69	$4\frac{1}{2}$″

A speed of 16 miles per hour would require 825 revolutions per minute of the motor shaft. The velocity at the pitch circle would then be 1080 feet per minute.

Lubrication. The question of lubricating the bearings is of great importance. The conditions under which tramcar motors work are very severe and from the nature of the case the bearings can only be examined occasionally.

It is usual to provide both oil and grease lubrication and a typical arrangement is shewn in figure 6. Ordinarily the bearing is lubricated with machine oil which is kept in contact with the shaft by a pad of felt attached to a spring of hard rolled brass. Should, however, the bearing get hot the grease is melted and supplies an additional source of lubrication. It may be mentioned that self-oiling bearings with rings are being tried.

N.B. The performance curves given in this Chapter have been calculated by the authors, and do not necessarily represent the official figures of Messrs Dick Kerr and Co.'s motor.

CHAPTER 3.

THE TRAMWAY CONTROLLER.

The tramway controller. In a general way the function of the tramway controller is to enable the driver of the car to regulate the action of the motors. The duties of the controller are, therefore, to start the car in either direction, to accelerate, to maintain the speed, and, when electric braking is used, to bring the car to rest.

The series parallel system. The simplest method of controlling the speed of a series motor is to connect it in circuit with a rheostat, and to reduce the external resistance as the speed rises.

Now, since the entire current flows through the rheostat, this is a wasteful method of control, as the energy put into the resistances cannot be utilised for propulsion.

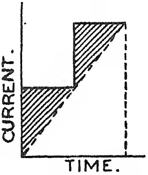


FIG. 7. Series Parallel Start.

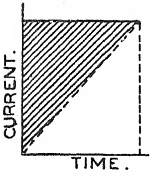


FIG. 8. Rheostatic Start.

With a pair of motors, however, a more economical method is possible. This consists in starting with the two motors in series, and when all resistance is cut out, and the motors are running at approximately half-speed, altering the connections so that the two motors are in parallel with each other, and in series with a resistance, and finally cutting out this resistance.

In the series grouping, the current taken by the two motors is only half what it is when the motors are in parallel. The loss in the rheostat is, therefore, considerably reduced.

Thus in the figures 7 and 8, the shaded areas represent the

rheostatic loss, shewing that with the series parallel method the efficiency of the start, neglecting the internal resistance of the motors, is 66·6 per cent., as against 50 per cent. for the plain rheostatic start. Or, putting it somewhat differently, the series parallel method eliminates 50 per cent. of the losses inherent in the rheostatic start.

The cycle of operations. The controller has, therefore, the following cycle of operations:

1. Switch on with motors in series and all resistance in.

2. Cut out resistance step by step. This is generally done in four or five steps.

3. Change the grouping from series to parallel, at the same time reinserting some resistance. This is generally effected by (*a*) reinserting resistance, (*b*) short circuiting one motor, (*c*) opening the short circuit in a different way, so that the motors are in parallel. This is shewn diagrammatically below (figure 9).

4. Cut out resistance step by step. This is generally done in three or four steps.

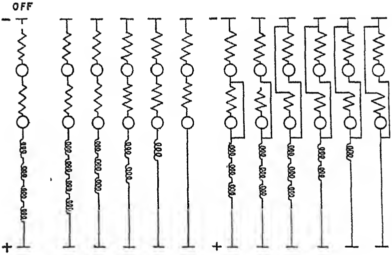


FIG. 9. Cycle of operations in Series Parallel Start.

The barrel type. Before going into more detail, it will be advisable to shew how this cycle of operations is carried out in practice.

The universal form of the tramcar controller is that of a barrel consisting of a number of contact pieces of suitable shape mounted on a spindle, and a set of fixed contacts or fingers, which press on the moving contacts. The barrel is so designed that, as it revolves, connections are made in the desired order between the various fingers. The latter are connected to the several points of the circuit including the motors and the rheostat, and in this manner the cycle of operations is performed.

In figure 10, the fingers are represented by short strokes arranged along the line XY, and the barrel is shewn in development to the left of this line. This figure shews the arrangement for a rheostatic controller.

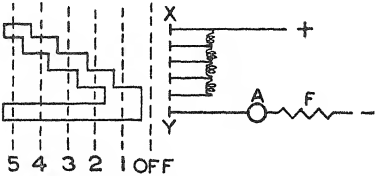


FIG. 10. Development of Rheostatic Controller.

In this case there is only one contact piece on the barrel shaped as shewn. The six steps are marked with dotted lines, which indicate the positions taken up by the line XY as the barrel is turned round.

In the off position, no current can pass; in the first position the two bottom fingers are connected and current flows from + through all the resistances and through the motor. As the barrel revolves, successive portions of the resistance are cut out, until in the last position the top and bottom fingers are connected and current flows direct to the motor.

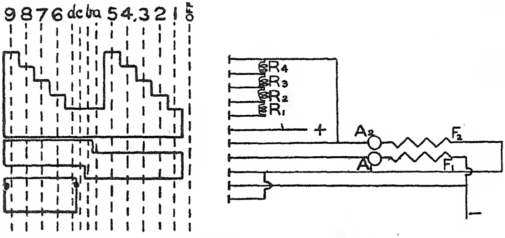


FIG. 11. Development of Series Parallel Controller (Motor short circuited during transition stage).

Using this same method of depicting the scheme of connections, figure 11 represents the arrangement for the series parallel cycle of operations described above.

In this diagram A_1, F_1 represent the armature and field winding of one motor, A_2, F_2 those of the second motor, R_1, R_2, R_3, R_4 the inserted

resistances, and + and − the positive and negative connections to the supply circuit.

It will be seen that the barrel consists of three separate pieces, insulated from each other and from the spindle. This barrel has five positions in the series connection indicated by the dotted lines 1—5, four transition steps *a*, *b*, *c* and *d* for changing from series to parallel, and four steps in the parallel connection, 6, 7, 8 and 9. The arrangement of fingers is clearly shewn by the diagram.

In position 1 current flows from + through the barrel to R_1, thence through the resistances to A_2 and F_2; thence through the middle piece on the barrel to A_1 and F_1; and finally to the negative pole −. In positions 2, 3, 4 and 5 the steps of resistance are short circuited successively, in the last position the two motors being in series across the full voltage.

In position *a* the resistances R_1, R_2, R_3 and R_4 are reinserted; in position *b* the terminals of A_1 and A_2 are connected through the barrel, which has the effect of short circuiting the second motor A_2, F_2. In position *c* this short circuit is opened; and in position *d* the terminals of F_1 and F_2 are both connected through the barrel to the negative pole.

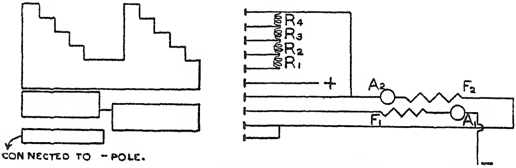


FIG. 12. Development of Series Parallel Controller (Motor circuit opened during transition stage).

The motors are now in parallel with the resistances in circuit, and the succeeding steps 6, 7, 8 and 9 cut out these resistances one by one.

Alternative method. The above method is open to the objection that the short circuited motor acts as a generator so long as its magnetic field continues. The current generated tends to demagnetise the field, but cannot do so instantaneously, and, in fact, current may still be flowing when the short circuit is opened. This action of the motor as a generator for the time being is liable to cause a jerk.

An alternative method of effecting the change of grouping is first to open the circuit, then to rearrange the connections without any short circuiting, and finally to close the circuit again. This method is shewn in figure 12.

Reversing barrel. To reverse the direction of rotation of a series motor, it is necessary to reverse the connection between the armature and the field winding. This requires four fixed contacts or fingers and a small barrel as in figure 13.

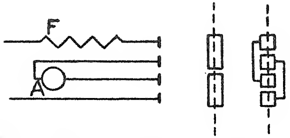


FIG. 13. Reversing drum for one motor.

It will be obvious on inspection that with the fingers along one dotted line the current in the armature is in one direction, and along the other dotted line the armature current is in the other direction, the current in the field winding remaining unaltered in both cases.

By mounting another row of fingers, diametrically opposite to the first row, the same barrel can be used to reverse the directions of two series motors as in figure 14.

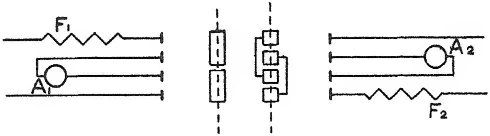


FIG. 14. Reversing drum for two motors.

Electric braking. If, when the tramcar is running, it is required to bring it to rest, the motors may be utilised as electric brakes. To effect this it is only necessary to disconnect the supply, reverse the motors and short circuit them through suitable resistances. The motors will then become self-exciting series generators driven by the momentum of the car, and by reducing the resistances as the speed falls a steady braking effect will be obtained.

There are two ways of connecting the motors for braking, viz. in series or in parallel. The former is objectionable on account of the excessive voltage that results at high speeds, and it is usual to employ the latter method.

With the motors in parallel, however, it is necessary to insert an equalising connection as in figure 15, in which XY represents the equalising connection. Without this precaution there would be, in all

probability, a large current circulating round the two motors without passing through the resistances. Thus, if one motor builds up its field faster than the other, it will overcome the other motor and magnetise it in the opposite direction and both E.M.F.'s will then be assisting in producing a large circulating current. The equalising connection XY prevents this by ensuring that the currents in the two fields shall be equal and in the same direction; thus the motor which builds up its field first helps to magnetise the other in the same direction.

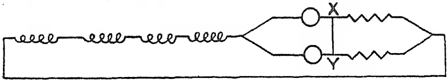


FIG. 15. Electrical Braking using equalising connection.

There is, however, another method of connecting the motors in parallel which does not necessitate any equalising connection. This consists in putting the armature of one motor in series with the field of the other motor as in figure 16,

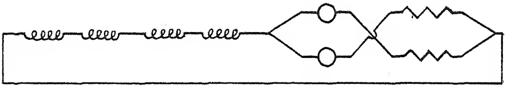


FIG. 16. Electrical Braking using cross-connected motors.

or as in figure 17.

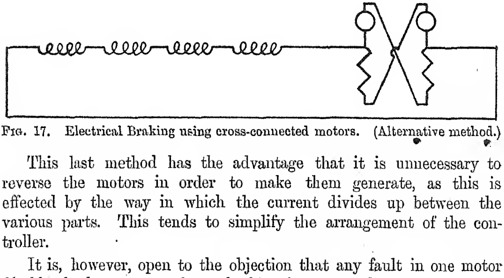


FIG. 17. Electrical Braking using cross-connected motors. (Alternative method.)

This last method has the advantage that it is unnecessary to reverse the motors in order to make them generate, as this is effected by the way in which the current divides up between the various parts. This tends to simplify the arrangement of the controller.

It is, however, open to the objection that any fault in one motor disables both motors as far as braking is concerned.

Cutting out defective motor. In the case of one motor breaking down, means must be provided in the controller for cutting it out and

using the other motor by itself. When this occurs, there can, of course, be no question of series parallel grouping. The single motor must be started rheostatically, and to permit this the defective motor must be replaced by a short circuiting connection. The controller must never be turned beyond the last series position, and it is customary to ensure this by suitable mechanical means instead of trusting to the memory of the driver.

If it is desired to arrange the controller for electrical braking with one motor only, both the short circuiting connection and the equalising connection must first be opened.

An alternative method of using one motor only is to dispense with any short circuiting connection and use only the parallel positions.

Controller in practice. Coming now to the actual carrying out of the requirements enumerated above, it may be said that the modern tramcar controller is probably the most compact, reliable and inexpensive piece of apparatus for the functions to be performed in the whole range of electric traction. It is the outcome of much experimenting and wide experience, and the various forms in use only differ from one another in details.

The chief parts are as follows:

1. The case.
2. The main barrel with its handle.
3. The reversing barrel with its handle.
4. The fingers and the finger-board.
5. The spark shield with the blow-out magnet.
6. Arrangements for cutting out defective motor.
7. The internal connections.
8. The terminal board.

The case is usually made of cast iron at the back and closed by a sheet iron front either hinged or fitting in grooves so as to make the controller practically water-tight. The case is lined throughout with asbestos. The casting at the back forms the support for the bearings of the spindles, and carries the whole of the mechanism of the controller. The top of the controller is a brass or gun-metal casting with the barrel positions marked on it. The ordinary tramway pattern has the following approximate dimensions:—height 3′ 0″, width 15″ to 16″, depth 9″. The main handle, when in the "off" position, points away from the operator at about 45° to the left.

The main barrel or power cylinder carries the various contact pieces, certain sections of which are connected together metallically, but all are insulated from the spindle. In some cases the spindle is square

in section, in others it is round with a flat on it to prevent the circular contacts from turning relatively to it. The insulation is of hard wood or of moulded insulation material. The circular contacts are gun-metal castings, with provision for renewing the copper portions or "tips" at each end of the arc as these become worn away in time. At the top of the main spindle and fixed to it is the star-wheel for making definite the different positions of the barrel, and for interlocking with the reversing barrel. The main handle is usually removeable and is provided with a projection which renders it impossible to remove it until it is placed in the "off" position. The stops which limit the motion of the main barrel are usually placed in the controller.

The reversing barrel is made of wood with the copper contacts screwed on to it. No provision is made for the suppression of sparks as this cylinder can only be operated when the main cylinder is in the "off" position. At the top of this barrel is fixed the gear which interlocks with the main barrel, and the handle cannot be operated or removed until the main cylinder is in the "off" position.

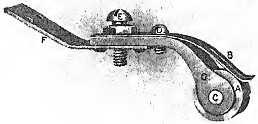


Fig. 18. Imeson's Finger.

The fingers consist of three or four parts: (1) the actual copper contact; (2) the fixed gun-metal base; (3) the spring connecting the contact and base; and sometimes (4) a flexible connection between the contact and base so that the current need not pass through the spring. Figure 20 shews a sectional plan of Messrs Dick Kerr & Co.'s finger-board, which is made of wood. It is screwed to the case and one of the fingers is shewn mounted upon it. A contact attached to the main barrel is also shewn. The width of the copper contact of the finger is $\frac{3}{4}''$ or $\frac{7}{8}''$ in an ordinary tramway controller. The distance between adjacent fingers is $\frac{7}{8}''$, which allows room for the insulating shield.

Imeson's roller contact finger illustrated in figure 18 is being tried by the users of controllers, and is stated to possess advantages over the older type.

The spark shield and magnetic blow-out form an important though not absolutely necessary part of the controller used for ordinary

tramway work. It is well known that, if an electric arc be formed in a magnetic field, the direction of the arc being at right-angles to the direction of the magnetic field, the arc tends to move in a direction at right-angles to both. As usually applied the magnetic field has a direction either parallel with the axis of the main cylinder, or at right-angles thereto. When the direction is parallel it is important to have the polarity such that the arc is driven away from the main cylinder. In the other case the arc is driven in a direction parallel with the main cylinder and impinges upon the sparking shield. In full series or full parallel positions the circuit which carries the main current and which produces the magnetic field may be short circuited, but at other times when the arcs are being formed at the contacts the short circuit is removed. The spark shield is shewn in plan in figure 20; and in elevation in other figures in this chapter. It is made of compressed asbestos and water-glass, or other arc resisting material.

The arrangements for cutting out a defective motor, sometimes referred to as "hospital switches," may take the form of (1) a small barrel with three positions, "both motors in," "number 1 out," "number 2 out," (2) separate switches, or (3) tripping devices for raising a finger off the main or the reversing barrel. In all cases interlocking is provided so that a motor can only be cut out when the main barrel is at "off."

The internal connections between the terminal board and the respective fingers and contact are fitted into a space between the main cylinder and the cast iron frame of the controller. The conductor used is a vulcanised rubber cable of 7/17 or 7/14 L.S.G. copper. The board is generally placed near the opening at the bottom of the controller, as shewn in figure 24.

Examples of actual Controllers.

Messrs Dick Kerr & Co. Figure 19 shews the standard tramway controller "DB. 1 Form C" made by this firm, in which S is the blow-out solenoid, PC the power cylinder, RC the reversing cylinder, and BC the brake cylinder. Figure 23 shews the connections and development of this controller in connection with the wiring of a tramcar of the simplest type, that is, for the case in which the rail is employed as a return and there are no magnetic brake shoes or "run-back preventer." The interlocking arrangements for the power and reversing barrels are shewn in figures 21 and 22. Before it is possible either to place the handle on the spindle of the reversing cylinder RC or to remove it therefrom, the cylinder must be in such a position that the power cylinder PC is locked in the "off" position. An arrangement on the top of the controller, figure 19, fixes the position of the

reversing cylinder at which its handle can be taken on or off. It consists of a projection on the reversing handle, which has to pass down through a slot in a circular lug cast on the cover before the handle can turn the cylinder. Once the projection has passed through

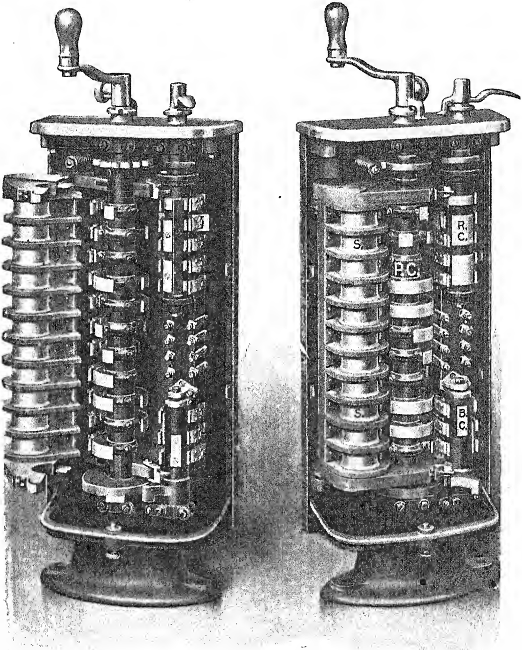


FIG. 19. Dick Kerr "DB. 1 Form C" Tramway Controller.

this slot the handle can be turned to the forward or backward positions. A further condition must be that when the reversing handle is in either the forward or backward position, and when the power barrel is in any position other than the "off" position, it must be impossible to

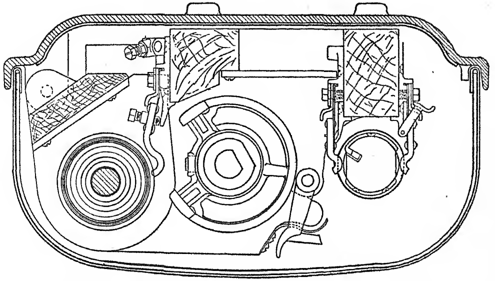


FIG. 20. Section of Dick Kerr Controller shewing barrels, fingers and blow-out.

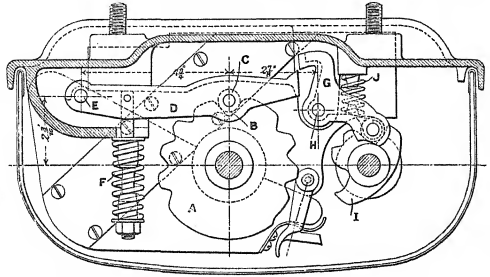


FIG. 21. Section of Dick Kerr Controller near top shewing interlocking gear.

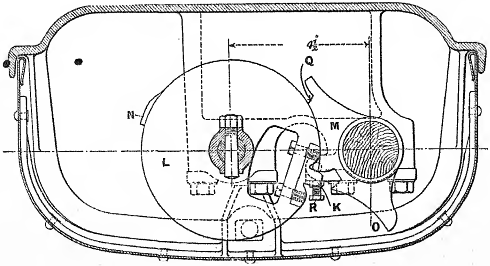


FIG. 22. Section of Dick Kerr Controller near bottom shewing interlocking gear.

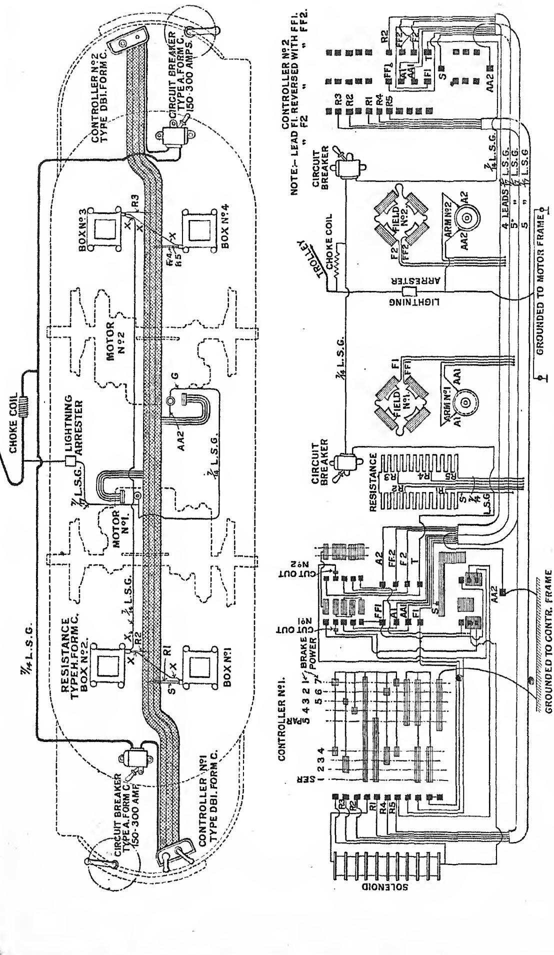


Fig. 23. Wiring Diagram and Development of Dick Kerr "DB. 1 Form C" Tramway Controller.

operate the reversing barrel. Fixed to the top of the spindle of the power cylinder PC is a star-wheel A (figure 21) with one depression B deeper than the rest. The pawl used takes the form of a small roller C attached to a lever D pivoted at E and held up against the star-wheel by a spring F. In figure 21 the wheel A is in the position it occupies when the cylinder PC is in the "off" position, that is, the pawl C is at its minimum distance from the axle of the power cylinder. A bell-crank lever G pivoted at H can be actuated by a cam I fixed to the reversing barrel RC and kept up against the cam surface by a spring J. The cam I is in the position it would occupy when the barrel RC is at the "forward" position. Under these circumstances the main barrel can be operated, as the lever D is not impeded: on the other hand, if the power barrel is at any position other than the one shewn the reversing barrel cannot be moved, as the lever D would stand too far from the axle of the power cylinder.

The arrangements for operating the brake cylinder BC and for stopping the power cylinder in its extreme positions are shewn in figure 22. The brake cylinder BC is operated by a tooth K on a locking disc L fixed to the bottom of the power cylinder. The figure shews the power cylinder in its "off" position and the tooth K is just ready to engage the stop plate M should the power cylinder be moved in a counter clockwise direction for braking purposes. This movement turns the brake cylinder BC, thus making the requisite connections. The stop plate M is so designed that the brake cylinder cannot be moved round on its axle except by the main barrel. The stop N comes in contact with a lug O cast on the stop plate M in order to prevent over-running the last brake notch. The stop N is, however, in a lower plane than the stop plate, otherwise it would not allow the power cylinder to operate throughout its whole range in a clockwise direction. The lug O is more clearly shewn in figure 19. To prevent over-running the last power notch the tooth K comes in contact with the stop plate M at the position Q. It may be mentioned that the screw R is for fixing the copper conductor to the frame of the controller.

This controller has seven power and five brake notches, three of the notches serving for both power and brake, and if the development be studied it will be seen that when passing from the series to the parallel combinations the whole circuit is broken. Two of the transition positions are converted into notches for *brake* purposes, but for *power* purposes all the transition positions are passed over rapidly. The power cylinder is shewn in section in figure 20, and is divided longitudinally into three parts, insulated from one another and from the main spindle. The upper section has seven segments which control the resistance in circuit and the blow-out solenoid S. The

remaining segments control the connections for series and parallel running. The blow-out solenoid S is a characteristic feature of this controller. It consists of an iron core shewn in section in figure 20, with a copper conductor wound in such direction that the magnetic field drives the arc away from the power cylinder. The arc in consequence impinges upon a ring of sheet copper, rapidly passes round its surface and is thereby extinguished. Figure 19 shews the series of copper rings with insulating flanges between them and the respective fingers. Contact with the solenoid is automatically made when the shield is closed

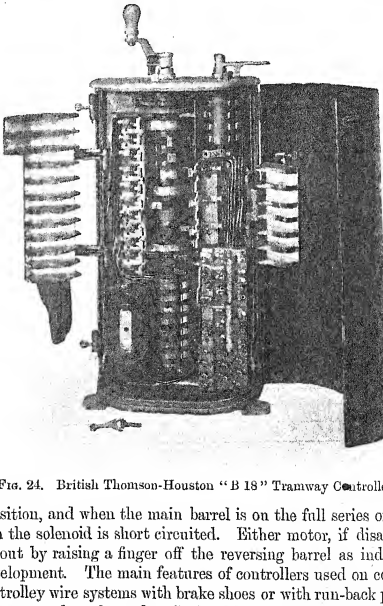


FIG. 24. British Thomson-Houston "B 18" Tramway Controller.

into position, and when the main barrel is on the full series or parallel position the solenoid is short circuited. Either motor, if disabled, can be cut out by raising a finger off the reversing barrel as indicated in the development. The main features of controllers used on conduit or double trolley wire systems with brake shoes or with run-back preventer are the same as have been described. The "run-back" preventer is a device which when the main handle is in the off position short circuits the motors so that in the event of the car tending to run back it is immediately braked. Provision for magnetic brake shoes will be dealt with in connection with the Westinghouse controller.

The British Thomson-Houston Company. The type B 18 controller made by this firm for ordinary tramcar work is illustrated in figure 24, and differs in one or two respects from the controller just described. The magnetic field for suppressing the arcs at the contacts is formed between the case of the controller and an iron armature hinged in a similar manner to the solenoid shield in figure 19. The

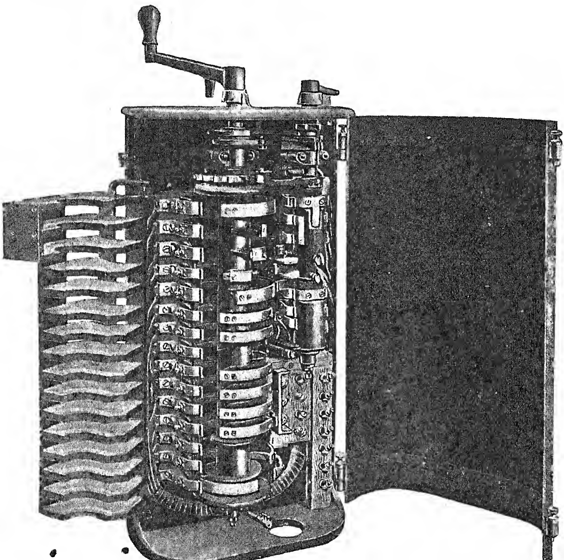


FIG. 25. British Westinghouse "90 M" Tramway Controller.

magnetic field is produced by the passage of the main current through the coil of wire on the iron core of an electromagnet which is screwed to the case of the controller, and which bridges across between the case and the bottom of the armature when the latter is closed into its working position. The direction of the magnetic field is therefore such that the arcs are driven parallel with the power cylinder, instead of away from it, and impinge upon the insulating shields. A subsidiary shield is provided

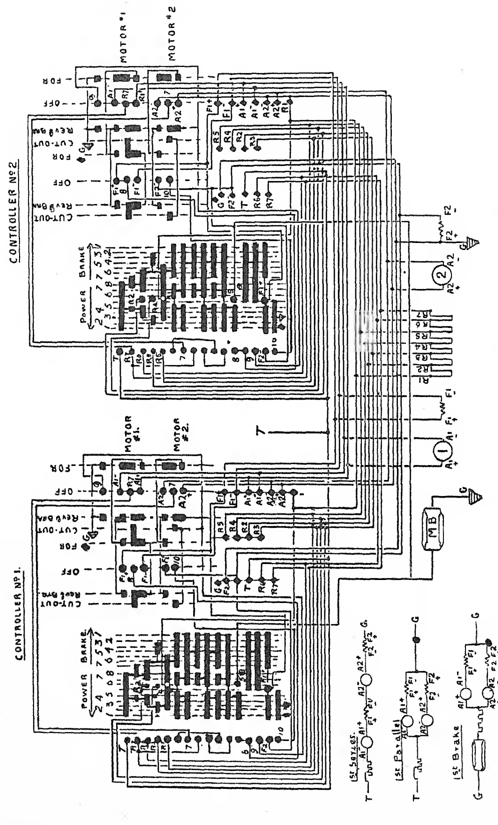


FIG. 26. Diagram of connections and development of British Westinghouse "90 M" Tramway Controller.

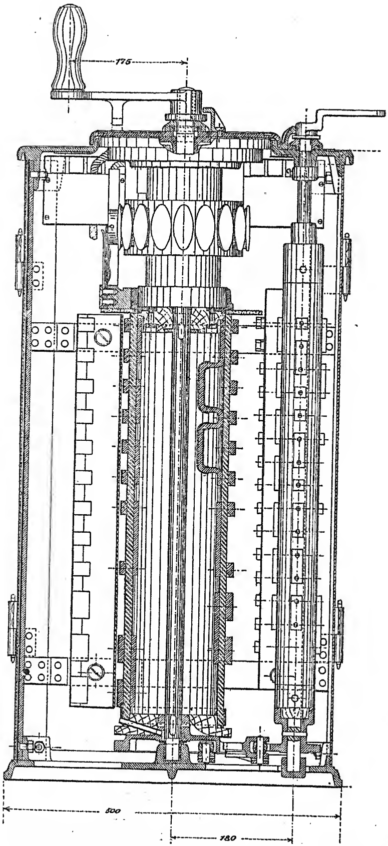


FIG. 27. Elevation of Siemens-Schuckert "N" Tramway Controller.

for the brake contacts and is shewn to the right of the power cylinder. As in the case of the Dick Kerr controller, this controller is designed to operate two 35 B. H. P. motors on the series-parallel system, where the rail is used as a return conductor. It is provided with four series, four parallel and six brake notches. The various combinations formed by the controller are the same as those already shewn in figures 9 and 15.

The British Westinghouse Company. The type 90 M controller designed by this firm for tramway work is similar in outward appearance to those above mentioned, and is illustrated in figure 25. Its development with and without magnetic brake and arranged for cutting either motor out of circuit is shewn in figure 26. Its characteristic feature is that it is not supplied with a magnetic blow-out arrangement, as the current is reduced sufficiently in magnitude by inserted resistance before the circuit is opened. If the development be studied it will be seen that the combinations for braking are the same as those shewn in figure 15. The diagram to the left of figure 26 shews the magnetic brake coils in circuit with the motors, when

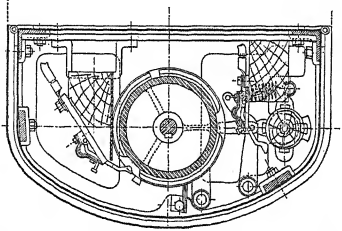


FIG. 28. Section of Siemens-Schuckert "N" Tramway Controller.

the controller is being operated on the brake notches. When used without magnetic brake shoes the finger S on the controller is grounded to the controller frame. The change from power to braking control is effected by mechanical connections between the power and reversing barrels. These connections are such that the movement of the power barrel into the first braking position turns the reversing barrel into its other position so that the motors are thereby converted into generators.

The Siemens-Schuckert tramway controller is illustrated in figures 27 and 28, and the diagram of connections and development are given in figure 29. It differs in several essential details from those controllers already described, the differences being particularly interesting as this controller is of German design, whereas the foregoing types are all of American or English origin.

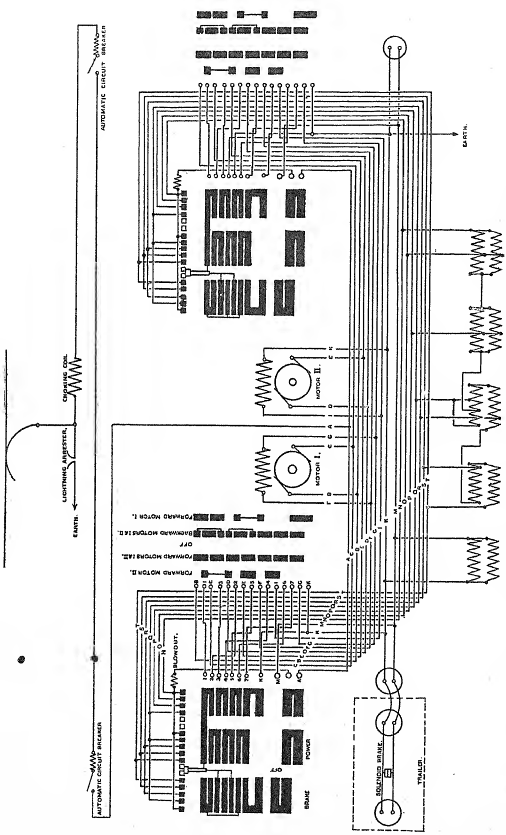


FIG. 29. Diagram of connections and development of Siemens-Schuckert "N" Tramway Controller.

The chief differences are (1) the arrangement and construction of the main barrel, (2) the separation therefrom of the arcs formed on opening circuit, (3) the arrangement of the magnetic blow-out, and (4) the method of cutting out a defective motor.

The main barrel consists of a tube of moulded insulating material 150 mm. in diameter, to which are attached the contact segments. These segments are 10 mm. thick, so that the diameter over all is 170 mm. The tube with its contacts is mounted on a spindle as shewn in the drawing.

The special feature of the controller is the arrangement for cutting out the resistances. Close to the top of the main barrel, and concentric with it, is a crown of fixed contacts, each of which is connected to one of the steps of resistance. Fixed to the main barrel and moving with it is a special finger (called the "wander-kontakt") which slides over this crown of fixed contacts, and makes connection between the contact segments and the various resistances. An examination of the diagram will shew that the only place where an arc can be formed is between the "wander-kontakt" and the fixed contacts; that is to say, no arcs can be formed on the main barrel itself. For the suppression of the arcs a magnetic field is provided, the coil for which is situated inside the ring of fixed contacts; one pole of the field is within the ring and the other is formed by the mass of iron which moves round with the "wander-kontakt." Each individual contact of the fixed ring is easily renewable, and the "wander-kontakt" has a renewable tip.

The reversing barrel is of the ordinary construction and is interlocked in the usual way with the main barrel. It has, however, a special feature in that it has five possible positions; the central one for "off," those on each side for "forward" and "reverse" and the two extreme positions for cutting out either motor. It will be obvious that such an arrangement cannot provide for forwards and backwards running with either motor cut out; but it is considered quite sufficient to make provision for forward running only under such conditions. If backward running is required, the driver must go to the other end of the car and work the other controller.

The transition from series to parallel grouping is effected by opening the circuit entirely and subsequently closing it again when the different grouping has been established. By this means the connections between the main barrel and the ring of contacts is kept simple; if the usual method were adopted it would be very difficult to ensure that no arcs were broken on the barrel.

Figure 29 shews that provision is made for operating electric brakes on a trailer car. This feature is peculiar to continental practice where trailer cars are permitted.

CHAPTER 4.

OTHER DETAILS OF TRAMCAR EQUIPMENT.

The calculation of the starting resistances. The following is an approximate method of calculating the values of the resistances for the various steps of the controller.

Consider a simple rheostatic start, in which it is desired to maintain the average current in the motor at a constant value C throughout the period of switching on.

Suppose the controller has n positions, in the first of which the total resistance in circuit is

$$R_1 + r,$$

in the second $R_2 + r$,

and in the nth or last position $R_n + r$, or r;

where r is the resistance of the motor.

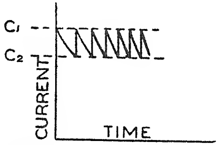


Fig. 30. Diagram of starting current for series motor.

For the purposes of calculation assume that the strength of the field in the motor is constant during the switching on; then, if C_1 be the maximum current and C_2 the minimum current, as in figure 30,

$$C_1 = \frac{E}{R_1 + r},$$

$$C_2 = \frac{E - e_1}{R_1 + r},$$

$$C_1 = \frac{E - e_1}{R_2 + r}, \text{ and so on};$$

and finally,

$$C_1 = \frac{E - e_{n-1}}{r};$$

E being the applied E.M.F. and e_1, e_2... being the back E.M.F.'s of the motor at the various steps.

From the above equations

$$\frac{C_1}{C_2} = \frac{R_1 + r}{R_2 + r} = \frac{R_2 + r}{R_3 + r} = \dots = \frac{R_{n-1} + r}{r},$$

and therefore $$\left(\frac{C_1}{C_2}\right)^{n-1} = \frac{R_1 + r}{r} = \frac{E}{C_1 r},$$

or $$\frac{C_1}{C_2} = \left(\frac{E}{C_1 r}\right)^{\frac{1}{n-1}}.$$

For a first approximation put $C_1 = C$ on the right of this equation,

and then $$\frac{C_1}{C_2} = \left(\frac{E}{Cr}\right)^{\frac{1}{n-1}}.$$

From this equation and from a second equation

$$\tfrac{1}{2}(C_1 + C_2) = C$$

the different resistances can be calculated in succession.

An example will shew the application of the method to a particular case, and, further, how the method is extended to a series parallel start.

Assume two motors with an average starting current of 50 amperes, and an internal resistance of 1·2 ohms per motor. Take 5 steps in series, and 3 in parallel. Let the voltage of supply be 500.

Then $$\frac{E}{Cr} = \frac{500}{50 \times 2 \times 1{\cdot}2} = 4{\cdot}17.$$

$\therefore$ to a first approximation

$$\frac{C_1}{C_2} = (4{\cdot}17)^{\frac{1}{4}} = 1{\cdot}43,$$

whence $$\frac{1}{2}\left(C_1 + \frac{1}{1{\cdot}43} C_1\right) = 50 \text{ or } C_1 = 59.$$

For a closer approximation

$$\frac{E}{C_1 r} = \frac{500}{59 \times 2 \times 1{\cdot}2} = 3{\cdot}53$$

and $$\frac{C_1}{C_2} = (3{\cdot}53)^{\frac{1}{4}} = 1{\cdot}37 \text{ whence } C_1 = 58.$$

Taking this value

$$R_1 + r = \frac{500}{58} = 8{\cdot}6 \text{ and } R_1 = 6{\cdot}2,$$

$$R_2 + r = \frac{8{\cdot}6}{1{\cdot}37} = 6{\cdot}28 \text{ and } R_2 = 3{\cdot}88,$$

$$R_3 + r = \frac{6{\cdot}28}{1{\cdot}37} = 4{\cdot}6 \text{ and } R_3 = 2{\cdot}2,$$

$$R_4 + r = \frac{4{\cdot}6}{1{\cdot}37} = 3{\cdot}36 \text{ and } R_4 = {\cdot}96,$$

$$R_5 + r = \frac{3{\cdot}36}{1{\cdot}37} = 2{\cdot}45 \text{ which should be } 2{\cdot}4, \textit{ i.e. } R_5 = 0.$$

Proceeding to the parallel steps, the average current is 100 amps. and the internal resistance of the motors in parallel is ·6 ohm.

Then $$\left(\frac{C_1'}{C_2'}\right)^2 = \frac{R_1' + r'}{r'} = \frac{E - e_n}{C_1' r'}$$

where e_n is the back E.M.F. of each motor when they are switched into parallel.

Now $$E - 2e_n = C_2 r = 42 \times 2{\cdot}4 = 101,$$

whence $$e_n = 199{\cdot}5.$$

For the first approximation, therefore,

$$\frac{C_1'}{C_2'} = \left(\frac{500 - 199{\cdot}5}{100 \times {\cdot}6}\right)^{\frac{1}{2}} = 2{\cdot}24,$$

whence $$C_1' = 138.$$

For a second approximation

$$\frac{C_1'}{C_2'} = \left(\frac{500 - 199{\cdot}5}{138 \times {\cdot}6}\right)^{\frac{1}{2}} = 1{\cdot}9,$$

whence $$C_1' = 131.$$

For a final approximation

$$\frac{C_1'}{C_2'} = \left(\frac{500 - 199{\cdot}5}{131 \times {\cdot}6}\right)^{\frac{1}{2}} = 1{\cdot}96,$$

whence $$C_1' = 132.$$

Taking this value

$$R_1' + r' = \frac{300{\cdot}5}{132} = 2{\cdot}27 \text{ and } R_1' = 1{\cdot}67,$$

$$R_2' + r' = \frac{2{\cdot}27}{1{\cdot}96} = 1{\cdot}16 \qquad R_2' = {\cdot}56,$$

$$R_3' + r' = \frac{1{\cdot}16}{1{\cdot}96} = {\cdot}592 \qquad R_3' = 0.$$

The external resistances are, therefore,

Series grouping		Parallel grouping	
Step 1	6·2 ohms	Step 6	1·67 ohms
,, 2	3·88 ,,	,, 7	·56 ,,
,, 3	2·2 ,,	,, 8	0 ,,
,, 4	·96 ,,		
,, 5	0 ,,		

Now, these values are all different, but it would add unnecessarily to the cost of the controller if each resistance in series and in parallel had its own contact. In practice there would be only 5 contacts, and the actual resistances must be adjusted so as to serve as well as possible for both groupings. For instance, the steps might be as follows:

Series grouping		Parallel grouping	
Step 1	6·2 ohms	Step 6	1·85 ohms
,, 2	3·6 ,,	,, 7	·7 ,,
,, 3	1·85 ,,	,, 8	0 ,,
,, 4	·7 ,,		
,, 5	0 ,,		

The complete determination of the resistances involves not only the calculation of their values but also a knowledge of their capacities.

The capacity of a resistance is expressed in terms of the watts it can dissipate without being overheated. Now the watts dissipated are expressed as C^2R, and therefore if R be known, it is necessary to specify the average value of C^2.

This value must be obtained from the conditions of service, viz. the weight of the car complete, the starting current per motor and the frequency of stopping and starting. The method of calculation will be shewn best by working out an example.

Assume the following data:

Weight of car equipped and fully loaded ...	10 tons
Average starting current per motor (2 motors)...	50 amperes
Average speed of car	8 miles per hour
Number of starts per mile	4

From the performance curves of the motor read off the speed and tractive effort corresponding to 50 amperes say, 1000 lbs. at periphery of a 30″ wheel, and 10·2 miles per hour.

From the above data calculate the total time taken in the start, and thence time on each step; from this calculate the watt seconds in each resistance. Thus:

Assuming rotational inertia at 10 per cent. of the weight of the car, and a constant tractive resistance of 20 lbs. per ton the acceleration will be

$$\frac{1000 \times 2 - 10 \times 20}{10 \times 2240 \times 1{\cdot}10} \times 32{\cdot}2 = 2{\cdot}36 \text{ ft. per sec. per sec.,}$$

hence the speed of 10·2 miles per hour (= 14·95 ft. per sec.) will be reached in $\frac{14{\cdot}95}{2{\cdot}36} = 6{\cdot}34$ seconds. The back E.M.F. per motor at this speed (assuming the same motors as before) $= 500 - 50 \times 1{\cdot}2 = 440$.

∴ under the circumstances the back E.M.F. rises uniformly at the rate of $\frac{440}{6{\cdot}34} = 70$ volts per second.

Taking the values of the resistances given above, and putting $C_1 = 58$, $C_2 = 42$, $C_1' = 132$, $C_2' = 68$, the back E.M.F. at each step can be calculated from

$$C_2 = \frac{E - e}{R_1 + r} \text{ or } C_1 = \frac{E - e}{R_2 + r}$$

(remembering that the back E.M.F. per motor is equal to $\frac{1}{2}e$ in series, and equal to e in parallel).

Series grouping

Step	$R+r$	$\frac{1}{2}(E-\overline{R_1+r}.C_2)$	$\frac{1}{2}(E-\overline{R_2+r}.C_1)$	Mean value	Time from start
1	8·6	70	76	73	1·05
2	6·0	124	127	125	1·8
3	4·25	161	160	160	2·3
4	3·1	185	180	182	2·6
5	2·4	199	—	199	2·83

Parallel grouping

Step	$R'+r'$	$E-(R_1'+r')C_2'$	$E-(R_2'+r')C_1'$	Mean value	Time from start
6	2·45	335	328	332	4·75
7	1·3	412	420	416	5·95

From these times the watt seconds are calculated thus:

Step	$R+r$	Resistance belonging to each step	Series			Parallel			Total watt secs.
			C^2R	secs.	watt secs.	C^2R	secs.	watt secs.	
1	8·6	2·6	6500	1·05	6800	—	—	—	6800
2	6·0	1·75	4370	1·8	7870	—	—	—	7870
3	4·25	1·15	2880	2·3	6610	11500	1·92	22000	28610
4	3·1	·7	1750	2·6	4550	7000	3·12	21800	26350
5	2·4	0	—	—	—	—	—	—	—

Now since there are stops every quarter of a mile, and the average speed is 8 miles an hour, there is one start practically every 2 minutes or more exactly every 112 seconds. Hence the average watts are obtained by dividing the total watt seconds by 112. Thus:

Step	Average watts	Resistance	Number of sections	Connection	Heat capacity per section
1	61	2·6	1—2·6	—	60 watts
2	70	1·75	1—1·75	—	60 ,,
3	255	1·15	4—·287	4 series	60 ,,
4	236	·7	4—·175	4 series	60 ,,

Thus there will be 4 sections at ·287 ohm, 4 at ·175 ohm, 1 at 1·75 ohms and 1 at 2·6 ohms, all of the same capacity, viz. 60 watts.

As an example, a set of resistances suitable for use with the Siemens-Schuckert controller described in the previous chapter may be quoted.

The resistances are as follows:

Series grouping	17·15	9·5	5·4	2·34	0
Parallel grouping		2·34	1·35	·55	0
Brakes	18·4	10·78	6·68	3·62	1·28

Assuming two motors each with a resistance of 1·2 ohms and a ratio

of maximum to minimum current of 1·69 for series grouping and 1·8 for parallel, the total resistances in these groupings should be

	19·6	11·6	6·86	4·05	2·4	series
and		3·5	1·95	1·08	·6	parallel

or inserted resistances

17·2	9·2	4·46	1·65	0	series
	2·9	1·35	·48	0	parallel

A compromise is made by using an inserted resistance of 2·34 ohms for the fourth series and the first parallel steps, and the third series step has an increased resistance so that the change shall not be too sudden.

For the braking connection the inserted resistances only differ from those in the series grouping in that each step has an added resistance of 1·28 ohms.

Resistances for tramcars. In practice, the resistances used for tramcar work are of three types, viz. spirals of wire, the cell type and the grid. The conditions of service are very severe, and necessitate a strong construction. The resistances are mounted under the car, and in order to reduce the weight as far as possible, are not enclosed, so as to take advantage of the ventilation due to the motion of the car.

For the wire spirals high resistance material is used, such as kruppin, which has a specific resistance about 80×10^{-6} ohms per cub. cm. The spirals must be short to prevent undue oscillation, and are supported at both ends by small porcelain washers fastened to an iron frame. This type of resistance is that most frequently used on the Continent, particularly in Germany.

Cell type of resistance. This consists of iron or nickel steel in strip form wound up spirally into a disc with strips of asbestos between layers. A number of such discs are mounted together on an insulated spindle.

A typical example has the following particulars and dimensions:

Width of strip	...$\frac{5}{8}$ inch
Thickness of strip, about	·02 inch
Outside diameter of disc	$8\frac{1}{4}$ inches
Distance between consecutive discs...	...1 inch
Number of discs	... 4
Resistance of each	·14 ohm

The discs are mounted together on a spindle and the whole clamped up into a supporting frame $8'' \times 10\frac{1}{2}'' \times 11\frac{5}{8}''$.

Each of the four units has a heat capacity of about 45 watts with a steady temperature of 100° C. above atmosphere in the shop, or probably about 75° C. above atmosphere when mounted under a car.

This type of rheostat has been used greatly in the past, but it has

the disadvantage that the asbestos is liable to disintegrate owing to absorption of moisture.

Grid type of resistance. This form, which has been introduced within the last few years, consists of a number of grids mounted side by side in a supporting frame. Each grid is a single casting of grey cast iron, covered with a coating of aluminium paint, or an alloy of aluminium and cast iron. Figure 31 shews the general arrangement, and the form of the grid; it will be seen that they are mounted by being strung on insulated iron rods. Units can be connected together in series or parallel by screwing on to the terminals brass or copper connecting plates.

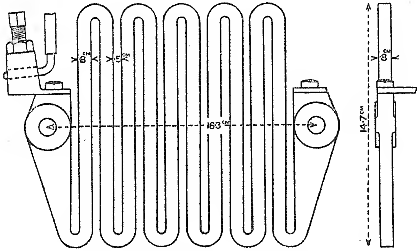


FIG. 31. Westinghouse Grid Resistance.

This type of resistance possesses several advantages; it is perfectly rigid; the terminals are accessible; it has no hygroscopic insulation; and the ventilation is very thorough. Moreover the material has a high specific resistance and a very low temperature coefficient.

An example of this type of resistance has the following particulars and dimensions:

Number of grids	8
Dimensions of each	$5\frac{3}{4}'' \times 8''$
Thickness of grid	...from $\frac{3}{16}''$ to $\frac{3}{8}''$
Thickness at lug	$\frac{1}{2}''$
Hole through lug	$\frac{3}{8}''$

Specific resistance, about...84×10^{-6} ohms per cub. cm.
Temperature coefficient, about ...·0008 per degree Cent.

Group	A	B	C
Mean length of grid, cm.	127	154	211
Cross-section, sq. cm.	·9	·64	·3
Number of grids	2	2	4
Connection	series	series	2 series, 2 parallel
Resistance of group, ohms	·024	·041	·057

Each grid has a heat capacity of approximately 40 watts with a steady temperature of 100° C. above atmosphere in the shops, or about 75° C. under a car.

In the British Thomson-Houston construction (see figure 32) the grids are insulated from the supporting rods, of which there are three, by micanite tubes, and the lugs are separated by micanite washers unless a metallic connection is required. The distance between the centres of

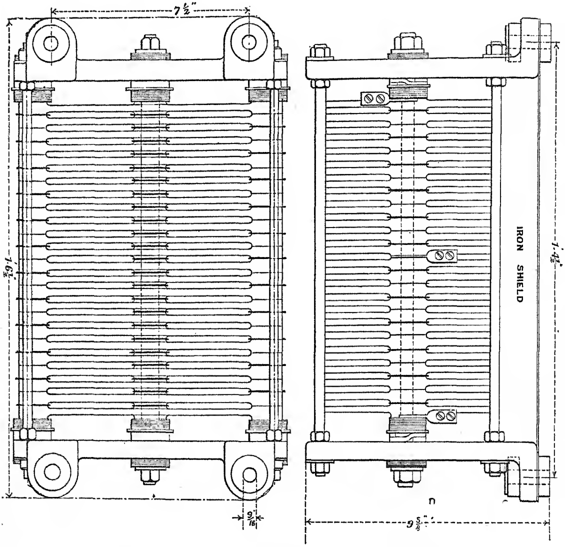


FIG. 32. British Thomson-Houston "GT" Grid Resistance.

the rods is 12 cm., the total width across lugs is 27 cm., and the height of grid is 17·5 cm. The thickness of the lugs is 1 cm. Contact is made at any point by placing a copper washer provided with a terminal between two adjacent lugs.

The wiring of an ordinary tramcar for power purposes has to be carefully carried out, and its arrangement requires the exercise of

considerable ingenuity. The diagram of connections in figure 23 shews one method of carrying it into effect. The cable is usually of the class 2500 megohms per mile and must be capable of standing the usual specification tests. A stranded conductor of 7/14 L.S.G. is connected to the choke coil of the lightning arrester and the poles of the circuit breakers at either end of the car, and from thence to the contacts marked T (trolley) on the controllers. A 7/17 L.S.G. conductor is employed for the remaining power-connections. In the particular equipment in figure 23 there are 3 composite cables running the whole length of the car: 2 containing 5 leads 7/17 L.S.G. and the remaining cable 4 leads 7/17 L.S.G. Each of these cables is connected to the respective terminals on each controller, and the resistances and motors are connected to them by tappings at suitable positions. The terminals are clearly lettered in the figure, and the reader will have no difficulty in following out the connections. It may be mentioned that a 7/14 L.S.G. stranded conductor has a carrying capacity of 35 amperes at 1000 amperes per square inch, and therefore gives adequate area for the requirements of a two 35 B.H.P. equipment, operated at 500 volts.

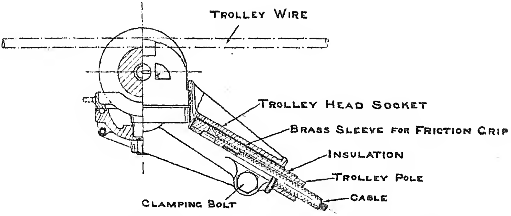


FIG. 33. Swivelling trolley head. (Brecknell, Munro and Rogers.)

The trolley head is fixed to the end of the trolley pole, from which it is insulated, and supports the **trolley wheel**, which collects current from the overhead wire. The wheel has a diameter varying from 3 to 5 inches, is made of gun-metal, and is sometimes provided with a steel centre. Except in the case of a "central" overhead wire, it is supported by a vertical spindle swivelling in ball bearings. A typical head is shewn in figure 33, and, complete with insulation, weighs about 8 lbs. The wheel must be designed to run with all types of frogs, crossings, and switches, and is automatically lubricated from a reservoir in the pin on which it rotates, or from a reservoir formed in the wheel itself. Graphite bushes are also employed.

A stop is usually fitted to prevent a complete revolution on the swivelling bearing. It is a good plan to fix the rope to a lug cast on the moveable head, as the conductor is better able by this means to get the groove of the wheel in line with the overhead conductor when replacing the head in position on the wire. In the case of a central running trolley the axis of the wheel is rigidly fixed to the pole and does not swivel.

The trolley pole and standard are designed to press the trolley wheel with a fairly uniform pressure against the overhead wire. In the case of double-deck cars it is necessary to raise the pole so that it can swivel about a point at a fair height above the car roof. For this purpose a standard is provided which is about $5\frac{1}{2}$ feet high, and usually consists of either a solid drawn steel tube firmly fixed into a malleable iron support, or the tube and support are one solid casting. Figure 34 shews a typical standard of the first type. The outer tube *a* supports the iron head *b* which is fixed to an inner concentric tube *c* and rests on ball bearings *d* about which the trolley can swivel. The inner tube extends to near the bottom of the outer tube, where it passes through a brass guide ring *e*. The internal spring *f* is used in compression and rests on a cup *g* having two lugs which move up and down in slots in the inner tube. The spring presses upwards against a fixed collar *h*. The tension screw *k* works in the cup *g* at the lower end of the spring, and is fixed to the cam on the pole-holder by means of links *l* and hardened steel roller *m*. The arrangement is such that as the trolley head is lowered a fairly uniform upward pressure is obtained since the leverage on the trolley arm is reduced as the force due to compression of the spring is increased. The casting to which the trolley pole is fixed is capable of movement about a steel pin passing through the head of the standard. The latter is provided with a set-screw to adjust the maximum height to which the trolley head can rise if it leaves the overhead wire (see page 438).

A typical support for the trolley pole in the case of single deck or canopy cars is shewn in figure 35, which illustrates a dwarf trolley standard constructed by Messrs Brecknell, Munro and Rogers. It has a total height of 4 inches when the pole is horizontal. The base is provided with a central sleeve on which is arranged a ball bearing connected to the rotating body. The pole-holder is hinged to the body of the support and is connected by steel tension screws to two compression springs, the degree of tension being adjusted by lock nuts. The weight of such dwarf trolley standards varies from 165 to 178 lbs.

Usually a straight through cable is employed in the above types of trolley, in which case a stop is provided to prevent the trolley pole

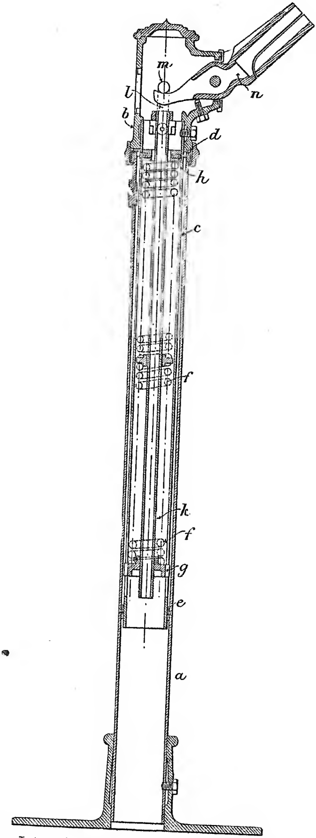


FIG. 34. Internal spring trolley standard. (Estler Bros.)

from being turned round indefinitely, thereby damaging the cable. Each type can, however, if desired, be fitted with a rubbing contact in order that the trolley head can be moved round indiscriminately. The section of a single deck or canopy car trolley given in figure 36 not only makes the construction clear, but shews Messrs Estler's arrangement of rubbing contact. The cable leading from the trolley head through the trolley pole terminates in a cone connection A fixed to a circular plate B which moves with the trolley head and is insulated from it by an insulator C. Another cone connection D attached to the cable which goes to the motor equipment is fixed to the socket E insulated from the fixed base by an insulator F. A concentric sleeve G is pressed against the plate B by means of a coiled spring and it is between the surfaces of these two pieces that rubbing contact takes place. The sleeve G is prevented from turning relatively to the socket

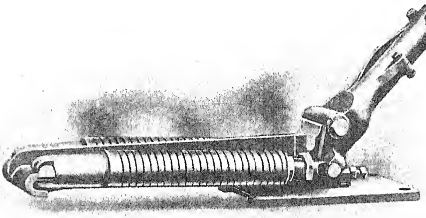


FIG. 35. Dwarf trolley standard. (Brecknell, Munro and Rogers.)

E by two screw pins working in slots, and a corrugated copper strip carries the current between E and G thereby preventing any heating which might occur at the joints. The interior can be filled with oil if desired. The trolley swivels about the fixed base, turning on a sleeve provided with double ball bearings. The ball races are in three parts and are made of oil hardened steel, the ring which is fixed to the swivelling head works between the two sets of balls.

In comparing different types of trolley standards with internal spring it is advisable to direct attention to the following points. The opening in the top of the standard in which the base of the trolley pole is pivoted should be so arranged with flaps or covers that water will not run into the interior of the standard. The base of the standard should be amply strong to withstand shocks, especially in view of the inspection hole near the base which takes away a good deal of metal. The

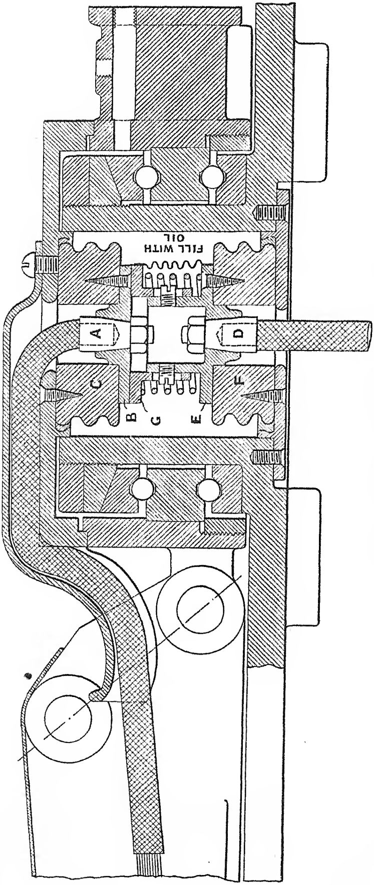


FIG. 36. Section of dwarf trolley standard. (Estler Bros.)

arrangement of the insulated cable and the internal spring should be such that any oscillation of the spring cannot force the cable against the adjusting screw, otherwise the insulation may be pierced.

A typical specification for a trolley pole is as follows:—"The pole to be of seamless or lap welded steel 15′ 6″ long by $\frac{1}{8}$″ thick; outside diameter at bottom to be 2″ and at top 1″; to be covered with three layers of tape and varnished; to be tested horizontally for 24 hours with 45 lbs. weight at the smaller end; deflection not to exceed 6″ with no permanent set." For a working pressure on the wire greater than about 25 lbs. it is best to reinforce the pole by 6′ of tube inserted at the butt end.

The **Insulation** of the trolley head from the trolley pole, and the trolley pole from the standard is carried out in the following manner. Referring to figure 33, it will be seen that the gun-metal casting which supports the trolley wheel is insulated from the pole by a sleeve of insulation material. The insulating sleeve is compressed tightly by a bolt and nut, the casting being split along the length of the insulating sleeve. The pole is supplied at its other end, where it enters the pole standard (see figure 34), with another concentric sleeve of insulation material, and along its whole length it is heavily coated with tape and compound. The insulated cable which transmits the current from the trolley wheel to the car passes down the centre of the trolley pole, and terminates at the end of the pole, supported by the standard in a metal disc and at the other end in a gun-metal boss; each insulated from the pole by a bush of insulation material. The cable within the trolley standard is similarly supplied with a fixed contact insulated from the head by a bush of insulating material at the point n in figure 34, and is then continued down the centre of the standard to the motor equipment. Generally a run through cable is used, in which case the head of the standard is supplied with a stop to limit the motion of the head. Sometimes a rubbing contact is supplied after the manner described in connection with figure 36, in which case the contact is placed near the bottom of the standard. When the trolley head is placed in position contact is automatically made between it and the gun-metal boss at one end of the pole, and similarly a butt-contact is made between the ends of the copper conductors when the pole is pushed home into the trolley standard.

The trolley standard must be connected to earth by a low resistance fuse or automatic switch, and the warning signal when the fuse or switch opens should be an electric bell. (See page 437.) Various visual as well as audible signals are at present in use.

Pressure. It is important that the upward pressure exerted by the trolley pole should be frequently tested, and devices are in use for

automatically doing this when the cars are run into the car sheds. The pressure can be too great and too small, and requires adjustment from time to time. If the pressure is too great the wear is increased owing to the impact when passing over frogs, ears, &c., and to the arcing due to partial breaks of the circuit at the trolley wheel. Too small a pressure is liable to cause arcing due to insufficient contact between the trolley wheel and wire. The wheel is liable to leave the wire and this may lead to broken standards, to the pulling off of the trolley heads, and to damage of the overhead line. For these reasons detachable trolley heads should be provided (see page 437), and the upward pressure should be tested daily if possible. In the case of a central trolley wire the head which supports the trolley wheel is fixed, and the upward pressure is about 18 lbs. In the case of side wires the trolley head overhangs the car sometimes to a considerable extent and is then provided with the swivelling head pressing upwards with a pressure of from 18 to 24 lbs.

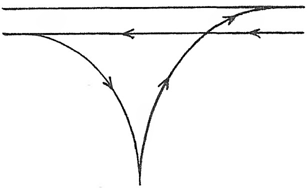


FIG. 37. Automatic trolley reverser.

Trolley ropes are provided for the purpose of pulling the trolley head down when reversing the direction in which the car has to run. Automatic Trolley Reversers are however being tried, and consist of a system of overhead construction such that when the car reaches a terminus the trolley wheel is run past a **V** extension at the side of the trolley wire. On reversing the direction of the car the trolley wheel runs out to the apex of the **V** and then inwards to the other trolley wire. (See figure 37.)

In the event of the wheel running off the wire the pole is prevented in some cases from suddenly rising by the intervention of some form of trolley pole catcher, of which there are several types on the market. The principle of all the types is that so long as the rope hanging from the pole only moves up and down slowly it has free play; if the trolley wheel leaves the wire and rises suddenly the rope is gripped. Where trolley ropes cannot be dispensed with or

tied up, precautions must be taken to prevent the "slack" causing accidents. (See page 437.)

The bow collector. Although in this country and in the United States the only type of current collector on tramcars in general use is the trolley wheel, on the Continent the bow type introduced by Messrs Siemens and Halske is often seen. The principle on which this collector is constructed is to provide a sliding surface which shall rub against the overhead wire.

One form of the bow is shewn in figure 38, in which various dimensions are given. As will be seen it consists of a frame pivoted at the bottom and carrying at the top a curved contact piece 1100 millimetres long. The frame is built up of light Mannesmann steel tube in the manner indicated, and the contact piece is of aluminium containing a groove filled with grease whereby the rubbing surfaces are to some extent lubricated. The whole collector is pressed upwards by the coiled spring at the base and tends always to rise to a vertical position. In normal working with the ordinary form the inclination to the vertical is about 30 degrees, and the usual length $2\frac{1}{2}$ metres; when the tramcar reverses its direction of motion, the bow raises the trolley wire slightly and swings over to a similar position on the other side of the vertical. In this way there is no necessity to pull down the collector and swing it round to the rear of the car as with the ordinary trolley wheel type.

This collector has two advantages, first that it cannot leave the overhead wire, and second that it makes possible a considerable simplification of the overhead construction. The wire is not, of course, put up quite straight, but is staggered from side to side of the centre line of the track, the extreme positions being half a metre on each side; this prevents undue wear at a single point of the contact piece and spreads it out over the whole surface.

As will be seen later, in the chapter on the overhead construction for tramways, the support of the trolley wire at crossings and junctions is such that the angle in the wire at any point shall not exceed a certain value. This limitation is caused by the necessity for guarding against the wheel leaving the wire when passing such a point. With the bow collector, however, it is obvious that this limitation is unnecessary; however sharp the angle there is no tendency for the bow to leave the wire, and there is no shock to the overhead construction. The only condition therefore that need be regarded is that mentioned above, viz. that the wire should not deviate at any point more than half a metre from the centre of the track. With curves of small radius, this permits a very considerable simplification of the construction.

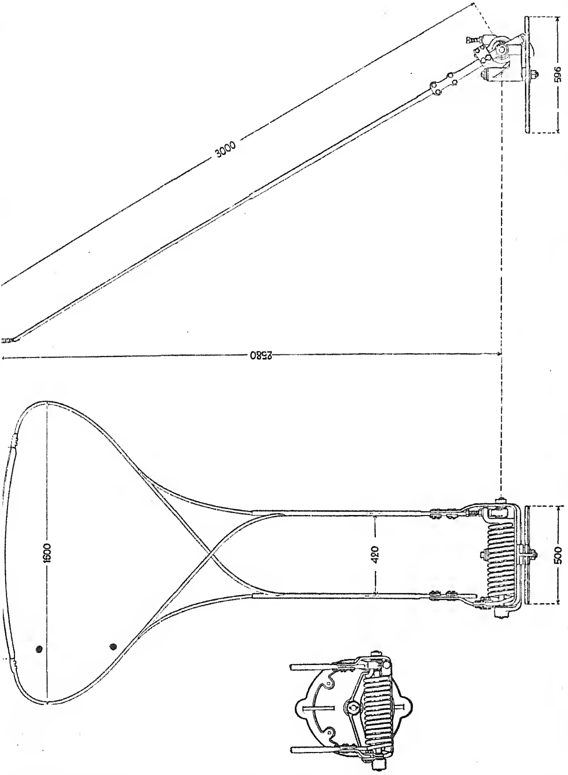


FIG. 38. Siemens-Schuckert bow collector (dimensions in millimetres).

The ordinary type of bow pivots about an axis which is fixed to the car roof; when the direction of running is reversed, the bow reverses also automatically. If however the trolley wire varies considerably in height this is not always possible; in such cases the base of the collector is made to swivel so that when necessary the bow may be pulled off the wire by means of a rope in the ordinary way and swung round towards the back of the car. It is held in one of the two fixed positions by means of a catch which engages with a slot in the fixed base, this catch disengaging when the bow is pulled down to the horizontal. This type is shewn in figure 38, in which may be seen the swivelling arrangement and the catch. An example of the use of this type is afforded by the Cologne tramways, where the trolley wire varies in height from 7·5 to 3·5 metres.

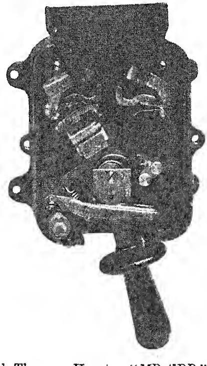


FIG. 39. British Thomson-Houston "MR 4DD" circuit breaker.

Other forms are in use to suit other conditions, as, for instance, in Sheerness, where the bow is carried at the top of a cast iron standard, and is thus made suitable for double-deck cars.

Automatic circuit breakers are placed in the circuit between the trolley and the motors and set to act at a current varying from 100 to 200 amperes according to the size of the equipment. If the wiring diagram in figure 23 be examined, two such breakers are shewn, one at each end of the car, and they should be within easy reach of the driver. Sometimes one automatic circuit breaker and one ordinary hand operated switch are employed, in which case the two are

in series, instead of in parallel as shewn. These breakers are fitted with blow-out devices, acting on the principle described in connection with controllers for tramways. Figure 39 illustrates a typical circuit breaker.

Lightning arresters are necessary on cars operated from an overhead wire, and several important forms are employed.

The **Garton** arrester is illustrated in figure 40, and combines the principle of an automatically lengthened air gap and magnetic blow-out. The gap is initially about $\frac{1}{16}$ inch long, between two *fixed* carbon rods, upon the upper one of which rests the plunger of a solenoid. The circuit between the trolley and earth contains an added resistance in the form of a fixed carbon rod connected at one end to the trolley and at the other to the upper extension of the iron plunger by aid of a flexible conductor. The lower carbon contact is connected to earth.

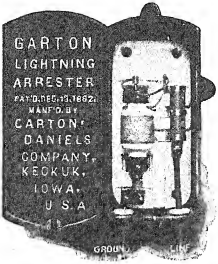


Fig. 40. Garton lightning arrester.

The ends of the solenoid winding are attached to two points on the fixed added resistance. When the lightning strikes, the line current immediately flows to earth, and in so doing produces a potential difference at the terminals of the resistance, and thus excites the solenoid. Its plunger is therefore sucked up, thereby opening up an additional gap, and the magnetic field produced by the current in the solenoid aids the elongated gap in suppressing the arc.

The **British Thomson-Houston** arrester is shewn in figure 41, and operates on the magnetic blow-out principle. The gap length, however, is fixed, and reliance is placed entirely on the magnetic field. This latter is produced between the poles of the electro-magnet shewn, between which the gap is placed when the cover of the arrester is in position. The excitation of the magnet coil is carried out in a similar manner to that in the Garton arrester.

The **Wurtz** arrester, manufactured by the British Westinghouse Company, is very simple and effective. It consists of two metal electrodes (see figure 42), mounted on a lignum vitae block, between which are charred grooves for providing a ready path for the discharge. The ohmic resistance between the electrodes is several thousands of ohms, and is therefore capable of resisting an arc maintained at the moderate pressure of 500 or 600 volts. A second lignum vitae block fits tightly over the grooves between the electrodes and leaves practically no room for vapour to be formed. It may be mentioned incidentally that this arrester works on diametrically opposite lines to the Wurtz arrester for alternate current circuits. The latter consists of electrodes made of an alloy which readily fuses and gives off such a dense vapour that the arc is suppressed.

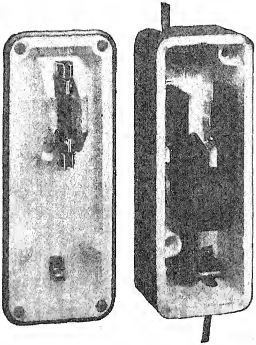


FIG. 41. British Thomson-Houston lightning arrester.

The **Shaw** arrester is an extension of the ordinary telegraph arrester. It consists of a number of carbon discs, insulated from one another, and mounted between two metal electrodes having sharp points like a saw. The arc which would otherwise be formed by the line current is divided up into a number of smaller arcs, and this is sufficient to suppress the current, at the same time allowing the lightning discharge to pass readily.

The **Ajax** arrester is another well-known type, and is provided with a number of air gaps formed between insulated copper wires, which become fused when the line current passes. The gaps are automatically brought into action, as they are burnt out by a falling weight. Re-fills of gaps are provided for insertion when necessary.

The choke coil consists of a few turns of wire through which the main current to the motors passes, and is placed between the trolley and the circuit breakers. Its impedance, when an oscillatory discharge of the frequency met with in lightning has to be dealt with, is very high; and it is a simple but effective protection against the lightning discharge taking the path of the motors or lamps to earth.

The lighting system of an ordinary double-deck car is arranged sometimes in three circuits between the trolley and earth, each circuit consisting of five 100-volt lamps, each of 16 candle power, in series. There are usually four inside lights, two roof lights, two canopy lights, four route indicator lights, two dash-board lights, and two signal

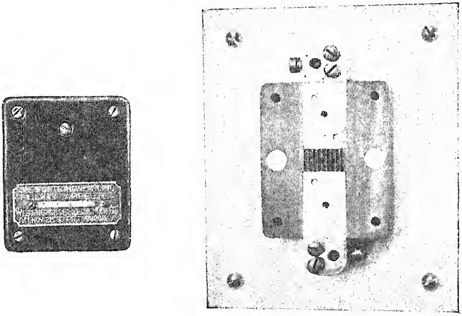


FIG. 42. Wurtz lightning arrester.

lights. The dash-board lights are connected in parallel, thus making an equivalent of 15 units. A switch and fuse are fitted in each of the three circuits, and the insulation well provided for by employing 2500 megohm class cable.

Messrs Siemens Schuckert supply with the lighting fittings lamp sockets which contain two extra contacts or "testing" contacts. In case any lamp filament breaks, the series of five are extinguished, and it is easy to ascertain which is broken by putting a spare lamp on to the "testing" contacts.

The Bells are worked by aid of a local battery, and about eight pushes are placed in convenient positions.

CHAPTER 5.

ROLLING STOCK FOR ELECTRIC TRAMWAYS, CAR BODIES, UNDERFRAME, TRUCKS, BRAKES.

A modern tramcar consists of

(1) The car body.

(2) The steel underframe.

(3) The truck, or the two bogie trucks, according to the length of the car.

The car body may be of the type supported on a four-wheel truck having a length of about 26 feet; or it may be of the type supported on two bogies, in which case its length is from 27 feet upwards. It may or may not be provided with roof seats. In the overhead trolley system the roof has to support the trolley and its standard. A description of these is given at pp. 50 etc., from which it may be gathered that sufficient strength is required in order that the stresses due to the weight and operation of the trolley may be successfully dealt with. The following is the specification for a typical top seat car, which is illustrated in figure 43, and is manufactured by the United Electric Car Co. of Preston.

Specification No. 2.

General dimensions.

	ft.	in.	mm.
Length of body	16	0	4877
Length of each platform	5	3	1600
Total length over buffers	27	5	8357
Width over sills for 4′ 8½″ gauge	6	0	1829
Width over window belts	6	7	2007
Width over roof	6	10	2083
Clear height inside at centre	6	9	2057
Over all height from rail	13	0	3962
Width of end door openings	2	1	635
Height of ,, ,,	6	1	1854
Gauge	4	8½	1435

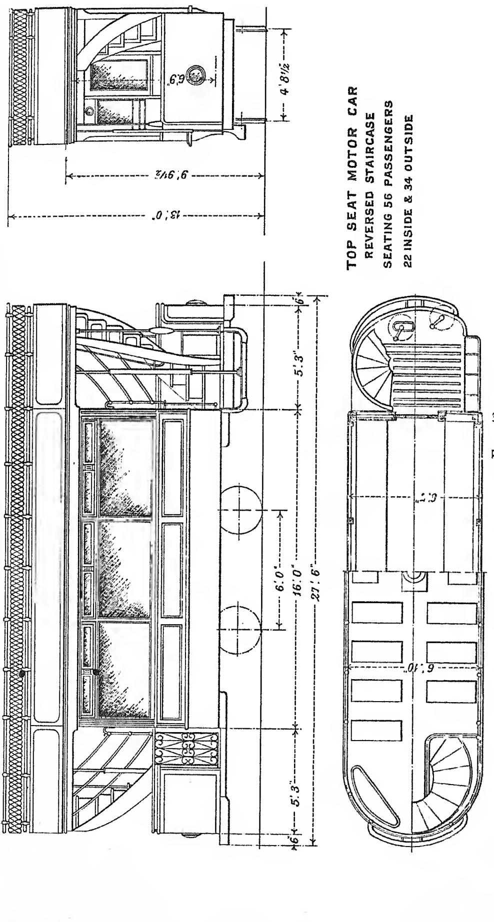

TOP SEAT MOTOR CAR
REVERSED STAIRCASE
SEATING 56 PASSENGERS
22 INSIDE & 34 OUTSIDE
4' 8½"
6' 9"
9' 9½"
13' 0"
6"
5' 3"
6' 0"
16' 0"
27' 6"
6' 10"

FIG. 43.

Seating capacity.

Inside	22	passengers
Outside	34	,,
Total	56	,,

General stipulations. These measurements refer to what is known as the reversed staircase type.

Framing. The floor frames are furnished in two different types of construction, a combination of wood and steel, or of steel only.

The main floor and the platform are laid with $\frac{7}{8}''$ tongued and grooved Carolina pine boards, and trap doors are provided over the motor openings.

The framing of the side and end walls of the car provide for ample ventilation through hinged ventilator windows placed above the fixed windows shewn on the drawing.

The end doors are of the single sliding type hung at the top on improved track and anti-friction roller hangers.

The main framing will be supplied in teak or American ash or oak as may be required.

Roof finish. The ceilings are furnished in millboard or three ply veneers faced with birds' eye maple, white birch or oak, as required.

The main panels will be supplied in teak, mahogany or whitewood, as required.

Platform equipment. Dashes No. 16 steel plates secured to wrought iron posts, and the top finished with rolled steel railings.

Collision buffers $3'' \times 6''$ steel channels bolted to the ends of the platform bearers and slotted for link and pin connection with trailer cars.

Brake staffs are provided with ratchet wheel and pawl above the headstocks, and with $10\frac{1}{2}''$ bronze ratchet handles at the top of the staff.

Foot gongs. Rolled steel foot gongs, 12″ diameter.

Steps. Steel steps, Stanwood, or other approved type.

Gates. Gates to be of the Pantagraph type.

Lockers are fixed under the stairways on opposite sides to the entrance steps.

The staircases are made up of sheet steel for the side stringers and risers, and wood treads, faced with iron (chequered) strips to prevent slipping.

The staircase hand-rails are supported by strong wrought iron stanchions, the top rail being of solid brass tube, polished, and the lower rail of best iron tube.

Roof equipment. The roof railings are made of the best iron tube and strong wrought iron standards fixed on each side of the car which carry the screen boards.

Roof seats of the garden type with angle iron legs screwed and stayed to the deck in a substantial manner. Seats of ash and the backs of one piece attached to reversing levers.

Trolley board. Provision is made for securing the trolley base to the roof in a thoroughly substantial manner.

Inside finish. Interior finish of oak and mahogany designed to give a substantial and pleasing interior. The main moulds are embossed, and over the end doors an ornamental headpiece is provided.

Seats. Inside seats—longitudinally—of oak lath and space type. The space underneath these side seats will be closed by a riser, which will conceal the motor cables.

All metal trimmings on the inside are of polished brass.

Blinds. Blinds are to be of the spring roller type and fitted to side windows.

Conductor's signal bells are secured to the underside of each canopy, and connected with the opposite platform.

Signal light. Over the right-hand end window there is provided a signal lens in connection with a metal frame arranged to carry glass of different colours.

Sand boxes. On each side at each end under the seats there will be a sand box of the Common Sense, Ham, or other approved type, set complete with foot pedal connections to platform and with spring wire cased tubes leading to rail.

Route indicators. Preston type, having removeable revolving linen screens, fixed to each canopy.

Painting. All painting of the finished exterior wood and ironwork will be primed, surfaced, coloured, decorated, lettered and finished with two coats of durable body finishing varnish.

Dash plates to have two coats of priming, two coats of paint, coloured, decorated, numbered and finished with two coats of durable body finishing varnish. Floors and platforms to receive two coats of priming and two coats of oil paint.

Inside finishing. All inside woodwork finished in the natural grain will have two coats of good filler and be finished with three coats of the best inside varnish rubbed to a natural gloss.

Completion. In general, it is the intended meaning of this specification to cover a completed car body fully prepared to receive all necessary electric apparatus. The same to be carefully boxed and packed for sea shipment.

When car bodies are more than about 27 feet long they are supported on two bogie trucks. A typical bogie car body has a length of about 32 feet and seating capacity as follows:

Inside	28	passengers
Outside	38	,,
Total	66	,,

Special requirements for foreign service. The "double service" car is so arranged that in summer the whole available window surface is used for ventilation. This is accomplished by constructing the windows very much as in an ordinary house, each half being capable of being raised sufficiently high to leave the whole side exposed for ventilation. Severe climatic conditions and wood-destroying insects require the use of teak in the construction, and this adds to the first cost of the car.

The steel underframe is the structure upon which the car body rests, and its importance in car construction cannot be overrated. The life of the car body depends largely upon the strength of the underframe, and yet its weight must be kept within reasonable limits. The design must therefore be such as to make the most of the material employed. Figure 44 shows the underframe used in the car just described, and the following is the specification:

Specification No. 3.

The underframe will be composed of steel channels well riveted. The solebars and headstocks will be composed of $6'' \times 3\frac{1}{2}'' \times \frac{1}{2}''$ and the crossbars of $6'' \times 2\frac{1}{2}'' \times \frac{1}{2}''$ section.

The headstocks will be slotted at the ends to receive the web of the solebar. The corner knees securing these members will be of steel and well riveted.

The first crossbar will be secured to the solebars by riveted steel angle knees and lipped under the solebar at each end to prevent any upward movement caused by the heels of the platform bearers.

Diagonal oak packings $6'' \times 2\frac{1}{4}''$ will be arranged for at each end. Openings will be provided for in the main floor for access to motors; the trap doors for motor openings will be carried on mild steel tees $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{3}{16}''$ bolted to crossbars.

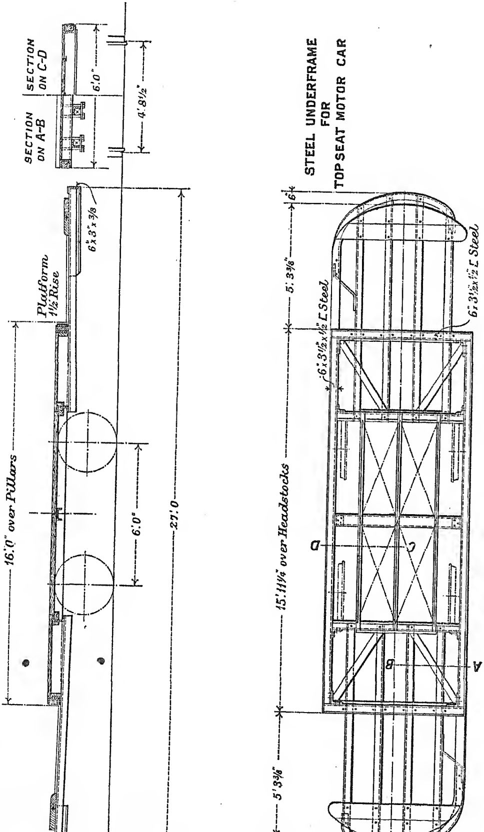

SECTION ON C-D
SECTION ON A-B
6'0"
4'8½"
STEEL UNDERFRAME FOR TOP SEAT MOTOR CAR
Platform 1½" Rise
6"x3"x⅜
16'0" over Pillars
6'0"
27'0"
6"
5'3⅜"
15'11¼" over Headstocks
6"x3½"x½" L Steel
6"x3½"x½" L Steel
6"x3½"x½" L Steel
A
B
C
D

Fig. 44.

The platform will have a rise of $1\frac{1}{2}''$, and will be carried by means of $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times \frac{1}{2}''$ steel angles attached to end crossbars and headstocks by means of $\frac{5}{8}''$ diameter bolts and flitch plates.

Bolted to the ends of the platform arms will be a steel channel $6'' \times 3'' \times \frac{3}{8}''$ bent to the platform radius to form a collision fender. This fender will be drilled and slotted and a pin will be provided for hauling the car in case of emergency.

All members of the frame and platform to be machined square and to length, and all riveting will be done in a thoroughly workmanlike manner by means of a pneumatic riveter. All holes to be drilled to template, and reamered where necessary.

It is perhaps appropriate to refer here to the recent requirements of the Board of Trade as regards folding steps (see p. 437), since these are supported by the underframe. In order to prevent overcrowding and consequent danger to life, it is advisable when a car is full to have a collapsible gate and folding step, which shall be under the control of the driver or conductor. There are various types at the disposal of tramway companies, and it is usual to operate the gate and step by aid of a lever and a pair of bevel wheels located in the base of the car.

The undertruck or bogie trucks support the underframe and car body, as well as the motor equipment. If the car is reasonably short it is possible to mount it rigidly upon a single truck, otherwise it is supported by two swivelling bogies. The choice of single truck or bogies depends upon the distance required between the axles or the "wheel base," and upon whether rigid axles or radial axles are employed. If the car is short enough to work satisfactorily with a 6 feet or 6 feet 6 inch rigid wheel base, a single truck is generally suitable for the curves usually found in tramway systems. A single truck may also be used with radial axles up to 10 feet wheel base, but unless such a construction is adopted swivelling bogies are required.

For example, on the Birmingham Corporation Tramways the cars on radial trucks are 29 feet long overall, and the cars on bogies 31 feet 6 inches long.

The rigid four-wheel truck. In principle, the rigid four-wheel truck consists of three separate parts or members connected together by two sets of springs. The three members are (1) the car body supports, which are bolted to the longitudinal girders of the undertruck; (2) the truck frame, which contains guides for the four journal boxes; and (3) the wheels and axles with the journal boxes. These three parts are connected together by two sets of springs, (*a*) the car carrying springs, by which the car body supports are attached to the

truck frame; and (*b*) the journal box springs, by which the truck frame is supported from the journal boxes and thus from the wheels and the rails.

It will be apparent, therefore, that between the track and the car body there is a compound spring system, the result being very smooth and easy running.

Within this general description there are several types having slight differences of design. These differences lie chiefly in the actual construction of the truck frame and the various springs. The truck frame is composed of the two side frames and two end bars, and is sometimes braced by means of diagonal tie bars across the centre, and sometimes by triangular or "gusset" plates at all the corners.

The following descriptions and illustrations shew several alternative constructions by various makers.

The truck serves also to support the electric motors, which are always geared to the truck axles. One side of each motor is supported by the axle, which is fitted with suitable bearings fixed on the motor, and the other side is suspended by means of springs from the truck frame.

The Preston No. 21E truck. This truck has been used in great numbers in this country, and is now manufactured by the United Electric Car Co. of Preston. Figure 45 shews diagrammatically the general arrangement of the truck in elevation and plan, from which it will be seen that the car body supports consist of two longitudinal flat bar irons called "top plates" (the bolt-holes for the steel underframe being shewn in plan) supported from the truck side frames by four helical springs and two elliptical springs on each side. These springs permit a vertical motion of the car body relative to the truck frame, this motion being limited downwards by the compression of the springs and upwards by the heads of the "spring posts," which pass through the helical springs and through the lower tie rods. These spring posts passing through holes in the side frames take the end thrusts, and prevent any horizontal relative movement between the car body and the truck frame. The spring posts are $1\frac{1}{4}$ inch round steel.

The frame itself is probably the most important member of the whole truck, as it has to withstand constant and severe shocks and stresses in every direction. It is absolutely necessary therefore that it should have great rigidity combined with reasonable lightness and cheapness. In this truck the frame consists of two side bars and two end cross bars secured at the corners by eight $\frac{7}{8}''$ bolts. The side bars are steel forgings made from bar billets, 4 inches square, forged to shape so as to form a single forging on each side of the truck. In each side bar two yokes are formed, in which slide the axle boxes, and the whole frame

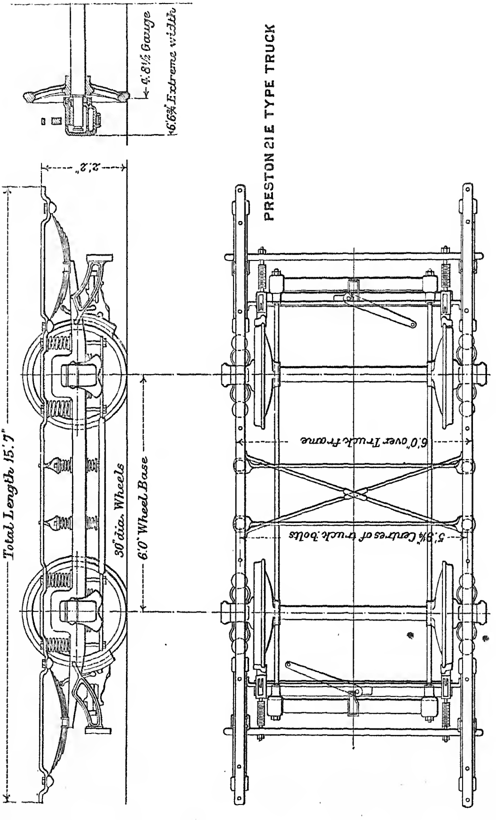

PRESTON 21E TYPE TRUCK
Total Length 15' 7"
30" dia. Wheels
6'0" Wheel Base
2' 2"
4' 8½ Gauge
6'6¾ Extreme width
6'0" over Truck Frame
5' 8¾ Centres of truck bolts

FIG. 45.

is braced together and stiffened by two diagonal bars across the centre of the truck. The axle boxes contain journal bearings of composite metal, and are shaped so that on each side of each box two helical springs are mounted, the bottom ends resting on the axle box and the top ends supporting the side frame of the truck. The journal boxes are of cast iron and are dust-proof; they are cored out to contain one quart of journal oil, which is applied by means of a felt oiler pressed on the journal by a brass spring. There are thus eight axle box springs, which together form the second part of the spring system.

The brakes are link suspended, the links having a slight angle so that gravity tends to release the brake shoes. The shoes are supported by eight $\frac{3}{4}$ inch round iron drop forged links, with their ends drilled for a $\frac{7}{8}$ inch pin. The upper ends of each pair of links are suspended from a malleable casting, which is lipped and bolted to the cross bars by $\frac{3}{4}$ inch bolts. The lower ends of the hangers are secured to the brake shoe holders by $\frac{3}{4}$ inch steel pins. The brake beam which connects the two

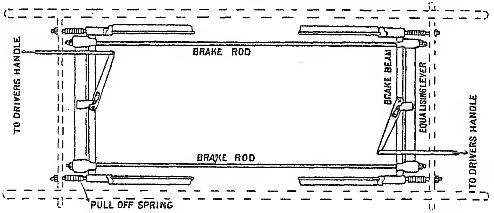


FIG. 46. Arrangement of brake gear on Preston No. 21 E truck.

brake shoes on one pair of wheels is a steel bar 4 inches by 1 inch, the equalising lever being of the same dimensions. The brake rods are of square iron threaded for 6 inches at the ends for the adjusting nuts. The brake shoes are of soft grey iron with five wrought iron pieces $1\frac{1}{2}$ inches long by $\frac{1}{4}$ inch half round let into the face of the shoe. The various brake parts are shewn in the sketch figure 46.

The following particulars refer to this truck:

Gauge	4 ft. $8\frac{1}{2}$ in.	or	1435	millimetres
Wheel base	6 ft. 0 in.	,,	1829	,,
Diameter of wheels	30 in.	,,	762	,,
Diameter of axle	4 in.	,,	102	,,
Diameter of journal	$3\frac{1}{2}$ in.	,,	89	,,

Shipping specification:

1 case containing 2 sides, end bars, brake beams, etc.
16 ft. 6 in. by 2 ft. 2 in. by 1 ft. 3 in.......1 ton 10 cwt. 0 qrs.
2 cases containing 2 pairs wheels and axles... 18 cwt. 2 qrs.
Total ...2 tons 8 cwt. 2 qrs.

This truck is suitable for cars the length of which is not greater than 27 feet over the dashboards.

Another type of rigid four-wheel truck is shewn in figure 47. This

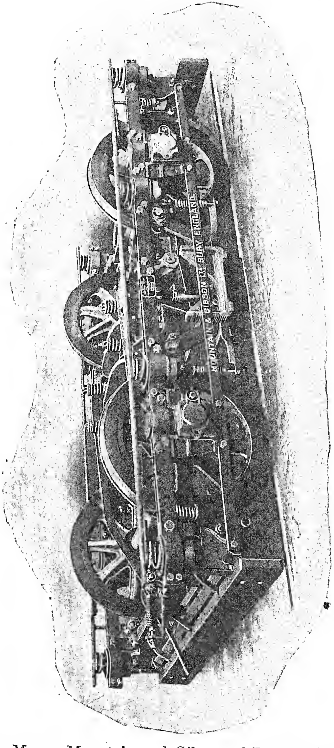


FIG. 47. Rigid wheel-base truck.

is built by Messrs Mountain and Gibson of Bury, and is suitable for track gauges up to 4 ft. $8\frac{1}{2}$ in. and for a wheel base from 5 feet to 6 feet. The car body supports or top plates are similar to those in the Preston

truck, and are attached to eight helical springs seated in pockets in the side frames. The motion of the car body relative to the truck frame is controlled by four draft plates fitted to the top plates working in guides between the steel bars which form the side frames. These draft plates take up the end thrust of the car. Bolts from the top plates through the side frames and through smaller helical springs serve to limit the upward movement of the car body.

The side frames are formed of solid forged steel bars bent to receive the spring seating both for the car body springs and for the axle box springs. Steel horn-blocks are bolted to these frames and also to the lower side bars, these members forming a complete frame on each side. The truck frame is completed with U-shaped end bars bolted to the side frames, and is braced up by diagonal bars across the centre. The four helical springs seen in the centre of the truck are fixed to the centre cross bars of the truck and support the beams, which are bolted to the motors.

Trucks of this type have been supplied to the Erith Council Tramways.

Figure 48 shews a drawing of another truck which is used extensively on the Continent; it has been adopted for the Cologne tramways and for the Warsaw tramway system, which is shortly to start working. It is manufactured by the firm of Van der Zypen und Charlier of Cologne-Deutz. The chief feature of this truck is the use of semi-elliptical plate springs both for the car body supports and for the journal boxes. It is claimed that with these springs oscillations are damped down sooner than with helical springs, owing to friction between the plates.

The following particulars relate to this truck:

Minimum radius of track	60 feet
Maximum speed	18·5 miles per hour
Gauge (in Warsaw)	5 feet
Wheel base	2 metres (6 ft. 6¾ in.)
Wheel diameter	0·8 metre (31½ inches).

The side frames A in this case are of pressed steel, shaped as shewn in the figure, the truck frame being composed of the two side frames and two steel channels B across the ends. The centres of the side frames are stayed by two channel iron cross beams *b* one above the other, and the whole frame is braced and stiffened by means of six gusset plates C, one at each of the four corners, and one at each end of the lower channel iron beam in the centre. The axle box guides are formed by two vertical angle irons D bolted to the side frames, slots in the frames being left for the movement of the axle boxes. The car body springs E are fixed at their centres to extensions of the end cross bars B and

at their extremities are attached by links to small pedestals which are bolted to the underframe of the car body. The axle box springs F are of the same type, being attached at their centres to the axle boxes, and at their extremities to links pivoted to the side frames. The fenders of wood G are supported from the frame by angle irons and joined together at their ends by similar wooden planks.

The motors are suspended in the usual way by cross beams of channel iron resting on helical springs supported from the side frames. The beam H is bent downwards at the sides so as to clear the brake rods and curved inward towards the helical springs K.

The brake rigging is clearly shewn in this drawing and consists of the following parts: the brake shoes L are pivoted to links M, these links being themselves pivoted at the points N to fixed brackets R, and to the equalising levers S. The brake rods T are likewise hinged to the equalising levers S and are operated by this means from the cross bar V. This bar receives the end of the chain attached to the driver's brake handle, the chain being guided by the pulley W. The action is as follows: when a tension is applied to the chain, the equalising lever turns about its intermediate pivot on the brake rod and applies the brake blocks to the near wheels. When these blocks come into contact the equalising levers turn about the brake block pivots and in the same way apply the pressure to the other pair of brake blocks through the brake rods.

Four-wheel radial axle truck. For tramcars which are too long for the rigid four-wheel truck a special truck has been introduced to meet the requirements incidental to a long wheel base and sharp curves. The special feature of this truck lies in the arrangement of the axles, which are not kept rigidly parallel to each other, but have a certain amount of freedom of movement; this freedom allows them to take up a radial position on sharp curves, thereby making possible the use of much greater wheel bases than are practicable with fixed axles.

The four-wheel radial axle truck manufactured by Messrs Mountain and Gibson of Bury is shewn in figure 49. This truck is built for track gauges up to 4 feet $8\frac{1}{2}$ inches, and for wheel bases from 8 feet 6 inches to 10 feet. The truck itself consists of the "intermediate" frame composed of steel channels stiffened and braced, the centre stiffeners carrying two king pins which form the pivots about which two sub-trucks radiate. These sub-trucks are independent of the intermediate frame being attached to it only at the pivoting points. The framing of the sub-trucks is of forged steel fitted with steel horn-blocks, within which are the axle boxes of the usual type.

The car body rests on the top plates, which are spring supported

from the intermediate frame by means of eight helical springs. The weight of the car body and the intermediate frame is taken by the sub-trucks through an arrangement of steel rollers working in separate

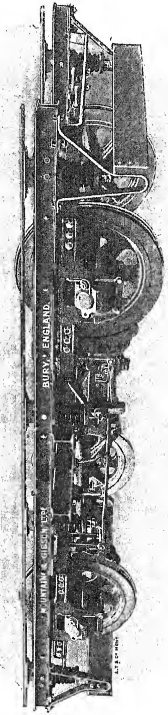


Fig. 49. Radial axle truck.

oil-baths; the underside of the intermediate frame being fitted with hardened steel rubbing plates working upon the rollers. The journal box springs are placed outside the horn-blocks and rest upon wings extending from the journal box.

The sub-trucks are provided with buffer bars at the outer ends, working between springs which ensure that the radiating trucks shall regain their normal positions after passing round a curve. The brake gear is of the equalising bar type with a brake block working upon each wheel; the brakes are controlled through a central floating lever supported by brackets hung from the centre of the truck, and the gear is arranged to radiate with the sub-trucks.

Maximum traction bogie truck. For long cars, the alternative to radial trucks is to use two bogie trucks, each of which has a short wheel base and is capable of movement relative to the car. This arrangement is in conformity with modern practice on rolling stock for full-sized railways; bogies of this class are dealt with in chapter 16, vol. I. to which reference should be made. In many cases of electric tramways, special bogies are used to meet special requirements. The chief point of difference between tramcars and railway motor coaches as regards the trucks, is that tramcars have to operate on very much steeper gradients, and, therefore, require as much adhesion as possible. On the other hand, it is the general practice to equip each car with only two motors, and in consequence, if the car is supported on two bogies, the weight available for adhesion is only a little more than 50 per cent. of the weight of the car. To mitigate this disadvantage bogies have been constructed for tramway work, in which the car body support is displaced from the centre of the truck towards the axle which is geared to the motor. Such trucks are called maximum traction trucks, and the proportions of the various parts are such that the weight available for adhesion may be as much as 75 per cent. of the total.

A truck of this description as manufactured by Messrs Mountain and Gibson for the London County Council Tramways is shewn in figure 50. The car body rests upon a central swivel plate which is hinged to the bolster. The latter is supported upon the bolster springs carried upon a spring plank suspended by links from the transoms. The side frames of the truck are of cast steel, the transoms are of channel steel and the bolster can be made as a complete steel casting or can be built up of steel plates. The motor is geared to the driving-wheel in the usual way, but the position of the motor is not as usual between the axles but outside. The spring support for the motor is provided by means of an end sill of channel steel at the end of the truck.

In the illustration the truck is shewn fitted with a magnetic track brake, and with two extensions of the side frames, towards the centre of the car, on which are mounted a pair of channels; in these channels slide the carrier of a plough collector as used on a conduit system.

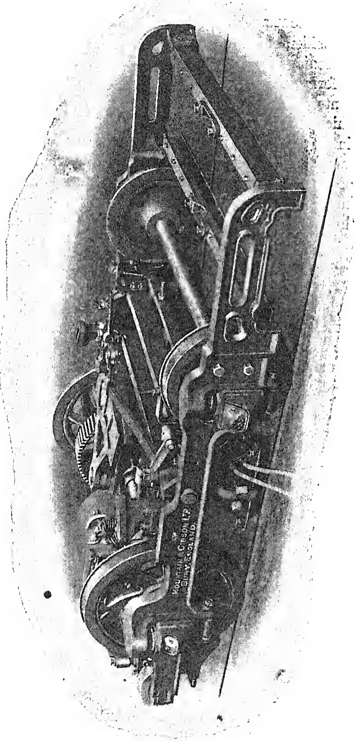


FIG. 50. Maximum traction bogie truck.

Motor suspension. The standard method of suspending the motor on the truck has been referred to several times, and is illustrated in figure 51. This figure shews the details of the suspension for a Dick Kerr motor.

Brakes for tramcars. The question of brakes for electric tramcars is one of considerable importance. Such tramcars may be considered as intermediate between horse-drawn vehicles and railway trains. For the former the ordinary hand brake is generally adequate for all requirements, whereas for the latter various brake systems have been devised which have been submitted to the severest tests before being brought into general use. In one respect electric tramcars are subject to more severe conditions even than railway rolling stock, in that in a few cases the tramway track is laid on an incline of 1 in 9 or 1 in 10. The control of speed on such an incline, more especially as the track is in the public road, is a matter of great importance. Several serious accidents have happened, due to cars running away down steep gradients, and the reports of the officer of the Board of Trade are very instructive*.

Another consideration in connection with the brakes on tramcars is the question of maximum speed. In each tramway system the Board of Trade imposes certain regulations (see p. 434) limiting the speed on different routes, or portions thereof, to certain values considered safe in view of the circumstances, such as the traffic, etc. These limiting values may be higher if a satisfactory brake is in use on all the cars than otherwise. An example of this is given by Mr Fell†, the chief officer of the London County Council Tramways, and is shewn by a comparison of the following figures, for his own tramway system:

Percentage of total length of track	23·07	57·55	17·5	1·63	0·25
Permissible speed without track brakes	12	10	8	6	4

and after a fresh inspection by the Board of Trade:

Percentage of total length of track	25·44	71·40	1·15	2·01
Permissible speed with track brakes	16	12	8	4

Of the various brakes in general use now, the plain hand brake is naturally the simplest. This is very often supplemented by means of the car motors, which can be converted into generators and in that condition act as powerful brakes (see also chapter 3). In some cases a special arrangement of the controller enables the motors to be connected up in such a way that backward running under the action of gravity on a steep incline is prevented. Of additional apparatus there

* See, for example, Colonel Yorke's report on the accident at Highgate Archway, reprinted in the *Tramway and Railway World*, Nov. 1, 1906.

† See the report in *The Electrician*, Jan. 26, 1906, page 590.

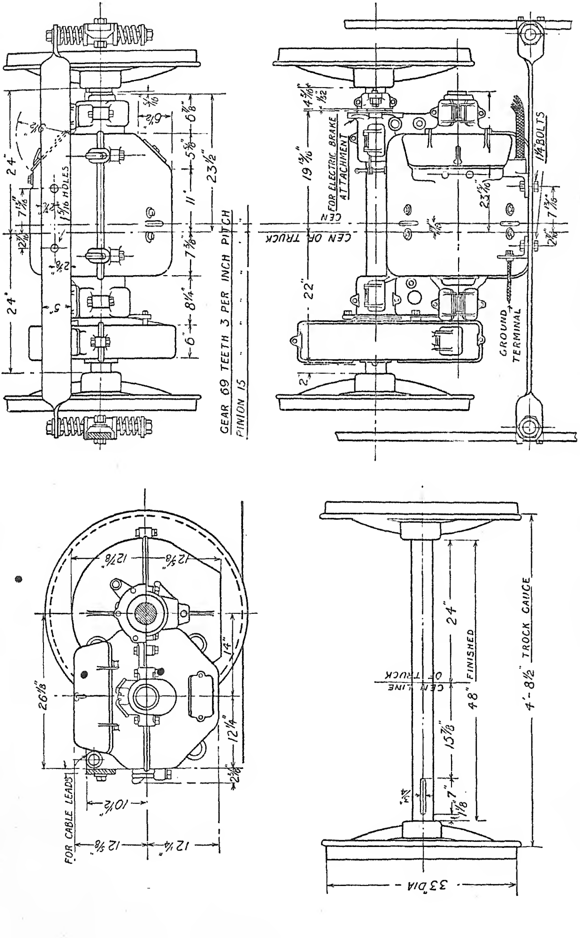


Fig. 51. Spring suspension for tramway motor. (Dick Kerr & Co.)

are several types, such as the slipper brake which is pressed on the track either by mechanical gearing from the driver's platform or by means of compressed air; there are also several forms of brake which are of an electromagnetic nature and are magnetised by current derived from the car motors acting as generators. Of these electromagnetic brakes three types may be mentioned, namely, the solenoid brake, the magnetic track brake, and the Newall magnetic track and wheel brake.

Run-back preventer. It has been explained in previous chapters that in order to convert a series motor into a generator it is necessary to reverse the relations of the armature and the field windings, as for instance by making the current flow through the field coils in the opposite direction to that in which it flows when the machine is a motor. If the relation between the windings of a motor is not altered the only alternative means of converting the machine into a generator is to reverse the direction of rotation. This property is taken advantage of in the run-back preventer which consists simply in arranging the controller so that in the "off" position the car motors are short circuited on themselves. If then a car is running forward up an incline and is brought to rest with the controller main barrel in the "off" position and the reversing handle left in the "forward" position, any backward motion of the car will cause the motors to generate, and as they are short circuited it will be impossible for the speed to rise beyond a very low value.

The "Peacock" brake. This is a special type of hand brake the essential feature being the use of an eccentric cam on the driver's brake handle. The shape of the cam is such that when the driver starts turning the handle for the application of the brakes, the chain is wound up on the cam at a large radius; as the handle is turned further the effective radius of the cam diminishes and consequently the leverage increases. By this means a complete application or release of the brakes requires much less turning of the handle than with the ordinary arrangement, and therefore takes less time, without any diminution in the braking power.

The mechanical track brake. This consists essentially of a wooden block which is pressed on to the rail by some means at the control of the driver. This means may be simply a combination of levers and screws or may be a pneumatic cylinder. In the latter form, known as the Hewitt and Rhodes pneumatic track brake, compressed air is supplied from a reservoir to the upper portion of a cylinder, the piston of which is connected to the wooden block. The general arrangement of this brake is shewn in figure 52, in which A is the cylinder with its piston and releasing spring. The wooden block is supported

by two hinged levers E and E′ which are connected at their inner ends to the piston rod. The maximum pressure that can be applied to the block is less than the weight of the car, so that there is little danger of derailment. Compressed air can be obtained from a reservoir charged on the storage system, or by means of an axle driven compressor.

The solenoid brake. This brake, which is manufactured by Messrs Siemens Schuckert of Berlin, consists of an electromagnet which receives current from the car motors working as generators and applies a powerful force to the ordinary brake rigging and to the brake blocks on the wheels. The retardation is due in this case to the combined effect of the brake blocks and the electromagnetic action of the motors working as generators. Two types of this brake are made called respectively S_6 and S_4. The former is used on cars equipped

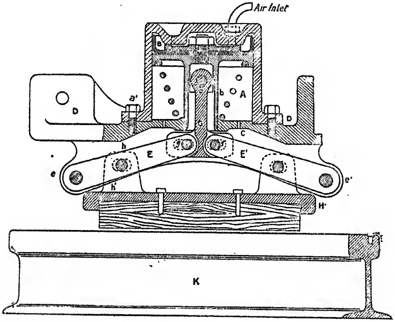


FIG. 52. Hewitt and Rhodes pneumatic track brake.

with motors and the latter on trailer cars up to 5 tons weight. The travel of the plunger in the former is 150 millimetres and in the latter 135 millimetres. The pull naturally varies with the current in the solenoid and with the position of the plunger, the maximum for the larger magnet being about 1300 lbs. and for the smaller magnet 900 lbs. The weights of the magnets are about 335 lbs. and 280 lbs. Fig. 29 shews how this brake is connected to the controller.

Magnetic track brakes. In principle, these brakes consist of electromagnets which are magnetised from the car motors, and when so magnetised are drawn down to the surface of the track rails by means of magnetic attraction.

Consider as a preliminary the possibilities of an electromagnet in the way of pull. Magnetic lines of force when crossing from one surface of iron to another parallel surface produce an attraction between the two surfaces of

$$\frac{B^2A}{8\pi} \text{ dynes,}$$

where B is the magnetic density (supposed uniform over the surfaces and throughout the gap which is assumed very short) and A is the area of each of the opposing surfaces in square cms. To convert into grammes weight this must be divided by 981, and further multiplied by $2{\cdot}204 \times 10^{-3}$ to convert into pounds weight. Thus the pull will be

$$\frac{B^2A}{8\pi} \times \frac{2{\cdot}204 \times 10^{-3}}{981} \text{ lbs. weight} = \frac{B^2A}{8\pi} \times 2{\cdot}24 \times 10^{-6} \text{ lbs. weight}$$

$$= \frac{B^2A}{8\pi} 10^{-9} \text{ tons weight.}$$

Now the head of an ordinary tramway rail is about $2\frac{1}{8}$ inches wide and the depth of the head is about $1\frac{3}{16}$ inches (standard rail 105 lbs. per yard). The total cross-section of the rail is practically 10·5 square inches; but it depends upon how close together the poles of a magnet are as to how much of this section is effective.

Let it be assumed that the electromagnet contains two poles separated longitudinally by about an inch; suppose each pole face to have an area of $2\frac{1}{8}'' \times 2''$, i.e. 4·25 sq. inches. (For such an arrangement this area may be assumed to be roughly equal to the effective area of the head of the rail.)

Let B be assumed as say 18000 lines per sq. cm. (a very high figure). Then $A = 4{\cdot}25 \times 6{\cdot}45$ sq. cms., and the pull per pole will be

$$\frac{(18000)^2 \times 4{\cdot}25 \times 6{\cdot}45}{8\pi} \times 10^{-9} \text{ tons} = {\cdot}35 \text{ ton.}$$

Thus the pull due to the electromagnet as a whole may amount to ·7 ton or 1570 lbs.

It should be noted that an increase in the cross-section of the poles will not produce much corresponding advantage unless the two poles be widely separated, because the magnetic flux will be determined by the cross-section of the rail-head. If the poles be separated sufficiently to utilise the full area of the rail, the length of the magnetic circuit becomes considerable, and the magnet tends to become unwieldy. In any case a definite limit is set by the saturation of the full section of the rail.

Now a pull of ·7 ton is not sufficient for practical purposes and therefore some fresh arrangement is necessary. There are two alternatives (*a*) the magnet may be arranged with longitudinal poles so

that the magnetic flux in the rail flows transversely instead of longitudinally, (*b*) the number of magnet poles may be multiplied without the section of each being increased. These two alternatives are those adopted by the two magnetic track brakes at present on the market.

The Newall track brake. In this form the electromagnet is practically a steel horseshoe with a minimum cross-section about 15 inches by 1 inch. The two poles are bent round together so that at the rail surface they are almost touching. The surface of the brake block is thus altogether about 30 square inches (actually 31·5 square inches), and it is possible to obtain a pull of 4500 lbs. per block (= 2·01 tons). This pull corresponds to a magnetic density at the pole surfaces of about 15800 lines per square centimetre, which is a moderate saturation and does not require an excessive number of ampere turns.

This brake is arranged as a combined track and wheel brake. The track brake adheres to the rails and produces thereby a retardation; this retardation acts directly on the car and indirectly through levers on the wheel brake blocks. The brake and its method of suspension and connection to the brake blocks are shewn in figure 53. The brake

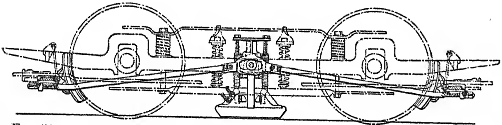


FIG. 53. Newall combined magnetic track and wheel brake. (Westinghouse.)

magnet consists of a horseshoe, the poles lying close together along the track; the ends of the poles slope upwards so as to enable the magnet to ride over any slight obstructions which might be encountered, such as granite setts standing up beside the rail. This is especially necessary for radial axle trucks; such trucks have a wheel base up to 10 feet and in going round a sharp curve, the magnet, which is mounted midway between the wheels, is bound to swing out a good deal from the line of the rails.

The magnet coil is contained in a brass case, which is first filled with oil and then sweated up. The pole shoes are detachable, being bolted on to the magnet core, and are separated at the rail surface by a wedge of hard wood.

From figure 53 it will be seen that the magnet hangs by two helical springs from a bracket bolted to the side frame of the truck. The two magnets on each truck are connected together by two cross-bars which

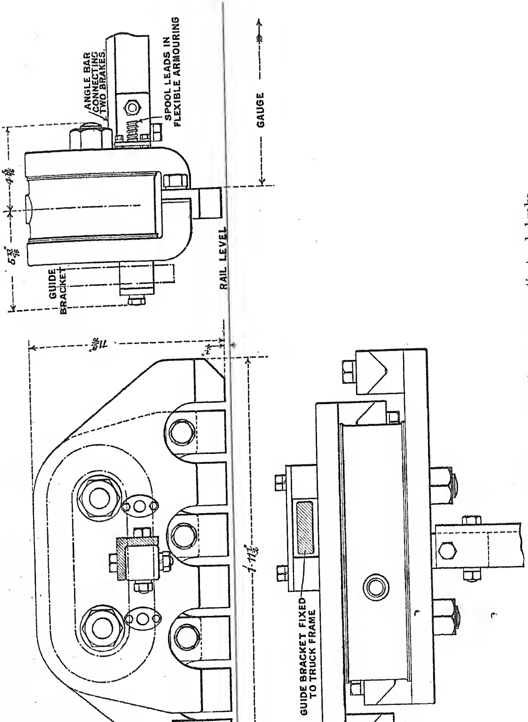


FIG. 54. British Thomson-Houston magnetic track brake.

serve to steady the magnets; between two projections on the inner side of each magnet is the tail of a lever pivoted to the side frame and carrying a cam in the shape of a star with four projections. Two brake rods, one from each brake shoe, are brought up to this point and overlap slightly, the arrangement being such that whenever the cam is turned in either direction by the movement of the magnet along the track, a tension is applied to each of the brake rods. This tension applies the brake shoes to the wheels and thus a double retardation is effected.

The British Thomson-Houston magnetic track brake (Form E and F) is illustrated in figure 54, and is designed for use on single-truck or bogie cars. The equipment for each car consists of one or two pairs of electromagnets provided with track shoes. Each pair of magnets is connected together mechanically by a bar spanning the track. The magnets are suspended from the truck frame by helical springs which hold them clear of the rails when not in operation. The thrust occasioned by the retarding action of the brake is taken on tongue-shaped steel brackets, bolted to the truck, which engage with jaws cast on the side of the magnets.

The magnet is of multipolar design, and consists of two main steel castings, which, bolted together, form a spool with deep elongated flanges. The lower edge of each flange terminates in a number of lugs projecting inwards, the two sets of lugs interlacing with each other but separated by air gaps. To these lugs the wearing shoes are fastened. They consist of blocks of iron or steel shaped in such a way as to facilitate renewal and provide a strong connection to the magnet. The coil is completely enclosed in a water-tight metal cover. The terminals of the coil are insulated leads covered with flexible armouring and arranged for connecting to the controller cables.

The brake can be applied by hand either in conjunction with or independent of the electrical application. This is arranged by a system of levers operated by a hand wheel on the car platform in much the same manner as the ordinary slipper brake. The levers apply pressure vertically between the truck frame and the top of the brake magnets.

General remarks on magnetic track brakes. The question of the best method of exciting the track magnets may be considered from several points of view, viz. safety and reliability, the heating of the motors, and the design of the magnet coils.

As far as safety is concerned, it is generally considered better to take the currents from the motors, working as generators, than from the overhead line. If a car starts to run away down an incline it

is quite probable that when the speed becomes excessive the trolley wheel will leave the wire. On the other hand, there is some danger that if the motors be used as generators, the driving wheels may be locked by the hand brake; in this case the magnet coil receives no current and the track brake is inoperative. Although this danger is a real one it is generally considered less than the former.

As far as the heating of the motors is concerned there is no doubt that to take the magnetising current from the line would relieve the motors of some extra duty. Against this, however, may be put the consideration that a magnet coil wound for a voltage of 500 to 550 is more expensive and more likely to break down from self-induction troubles, than a low voltage coil.

Taking it, therefore, for granted that the current is to be taken from the motors, it may be asked whether much or little current is to be taken. Probably the most important point of view is that there is a considerable advantage in being able to maintain the braking effects down to low speeds. For this purpose it is essential that the resistance of the magnet coils should be low, since the minimum speed at which the motors will generate depends upon the total resistance in the circuit. This, of course, requires a fairly large current in the exciting coils to produce the necessary ampere turns.

CHAPTER 6.

THE TRAMWAY TRACK.

The track. The line of rails must be considered from two points of view; as an electrical conductor and as a track on which the tram-car is to run.

Taking the latter consideration first, the rails are to be regarded simply as a support for the cars, and they must be such as to ensure smooth running and to stand the heavy wear and tear to which they are subjected without giving rise to excessive expenditure on maintenance.

When electric tramways were first introduced they came chiefly as electrifications of existing horse tramways, and the light rails used for these systems were made to do duty after the alteration. It became apparent, however, that the new conditions required much heavier rails, as the increased speed of the cars and their greater weights due to the heavy motors, which were necessarily only partly spring-suspended, soon wore away the light rails.

The modern practice is to have rails weighing about 100 lbs. per yard. These are laid on a bed of concrete and joined at their ends with strong fish plates. The type of tramway rail universally used in the United Kingdom is that known as the grooved girder rail, and is illustrated in figure 55. In America a girder rail resembling the ordinary flat-bottomed railway rail is sometimes employed, in which case the paving blocks have to be cut away in order that the wheel flange may be accommodated. Step girder rails are also used, and differ from the grooved type (figure 55) only in that the lip is not bent up to form a groove, but is kept straight out at right angles to the web surface.

The **Board of Trade** memorandum on details of construction and equipment (see page 436) states that the weight of the rails should not be less than 90 lbs. per yard, 100 lbs. being preferred. The groove of the rail should not exceed one and an eighth inch in width, but a groove not exceeding one and a quarter inch will be accepted on curves of less than 150 feet radius.

Figure 55 is a section of a girder type rail and fish plates ("BS" sections No. 4 and 4 c—105 and 111 lbs. per yard respectively), giving a few dimensions together with tyre profile. In this figure A is the width of a standard tyre, and is the only dimension of the wheel which varies with the weight of the rail. B is the gauge line for the rail, and C is the gauge line for the tyre. The 111 lb. section is used for curves and differs from the 105 lb. section as indicated by dotted lines. The above section has been taken from the British standard sections and specification for tramway rails and fish plates, dated July 1903, from which the following notes are also taken. A few of the leading dimensions and the weights of the fish plates are given in Table 1, below.

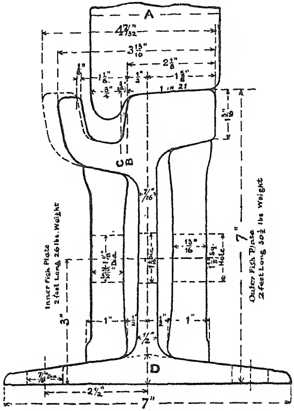


FIG. 55. Tramway rail ("BS" sections No. 4 and 4 c).

Rails. The steel for the rails shall be of the best quality, made by the acid Bessemer, basic Bessemer, or other approved process, and on analysis shall shew that in chemical composition it conforms to the following limits.

Carbon.........	from	0·40 to 0·55	per cent.
Manganese...	,, ...	0·70 to 1·0	,,
Silicon	not to exceed	0·10	,,
Phosphorus	,, ,, ...	0·08	,,
Sulphur......	,, ,, ...	0·08	,,

The normal length of rails for straight track shall be either 35, 45 or 60 feet, and for curved tracks 35 feet. The rails must be able to pass the following mechanical tests: (1) a length of 5 feet shall be cut from a rail selected out of each 80, and "shall be supported in a horizontal position, head uppermost, on solid iron or steel bearings, placed 3 ft. 6 ins. apart in the clear, on firm foundations." A ball or tup, weighing not less than 2240 lbs., having a face not greater than 9 ins. radius, is to be dropped from a height of 15 ft. for rails less than 100 lbs. per yard and 18 ft. for rails of 100 lbs. or over, in such manner

that the blow is to be transmitted vertically through the web, and the rail shall not fracture. If the first test is not satisfactory a similar test may be applied on two further pieces. (2) A tensile test shall shew an ultimate tensile strength equivalent to not less than 40 tons per square inch, with an elongation of not less than 12 per cent. on a length of 2 inches. In the event of failure of this test another rail from the same cast may be tested. In the event of failure the whole of the rails from this cast may be rejected. In addition to the holes necessary for the fish plates, joint plates and tie bars, two $\frac{3}{4}$ in. round holes have to be drilled in the web of the rail at each end for electric bonding. This provides for two bonds (0000 B. and S. gauge); the distance between centres of lugs being 2 ft. 5 ins. in each case. The holes for the bonds at each end of the rails are not vertically above one another, their distances from the butting surface being $13\frac{1}{2}$ ins. and $15\frac{1}{2}$ ins. respectively. Vertically the hole centres are $\frac{3}{4}$ in. above and $\frac{3}{4}$ in. below the horizontal centre line of the fish plate bolt holes.

It should however be noted that the holes for bonding purposes may have to be drilled to suit protected rail bonds (see page 107).

For fish plates three round holes, each $1\frac{3}{16}$ in. diameter, have to be drilled in the web of each rail, at each end. The centre of the hole nearest to the end of the rail is 2 ins. from the end, and the others are spaced 4 ins. between centres. In the case of $6\frac{1}{2}$ in. rails the fish bolt centres are $2\frac{3}{4}$ ins., and for 7 in. rails they are 3 ins. from the bottom of the flange.

For tie bars one oval slot (3 ins. by 1 in.) is made in the web at each end of the rail, the centre of the slot being 30 ins. from the rail end. Additional slots are made at such a distance apart as may be required, generally about 9 ft. The centres of these holes are in all cases $2\frac{3}{4}$ ins. from the bottom of the flange.

For joint plates, six round holes each $\frac{7}{8}$ in. diameter are drilled in the flange of the rail at each end, at the same pitch as the fish plate bolt holes. Transversely the distance between centres is $4\frac{5}{8}$ ins. for $6\frac{1}{2}$ in. flanges and 5 ins. for 7 in. flanges.

For intermediate plates six round holes, each $\frac{7}{8}$ in. diameter, are drilled in the flange of the rail, midway between its ends—pitch 6 ins. longitudinally and the same transversely as for similar holes at the ends.

All the holes have to be drilled except those for tie bars, and these may be punched.

The relation between electrical conductivity and composition of steel is dealt with at page 389, but it may be here mentioned that, in the case of tramways where the wear is very considerable, it is

TABLE 1.

Dimensions of British Standard Sections, Tramway Rails and Fish plates.

Tramway rails												Fish plates		Remarks
"BS" Section	Lbs. per yd.	Depth of rail	Width of flange	Thickness of web		Thickness of flange		Face width	Head width	Groove		Weight of inner plate	Weight of outer plate	
				Top	Bottom	At edge	At centre of web*			Width at top	Depth			
		ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	lbs.	lbs.	
1	90	$6\frac{1}{2}$	$6\frac{1}{2}$	$\frac{13}{32}$	$\frac{15}{32}$	$\frac{9}{32}$	$\frac{21}{32}$	$3\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$22\frac{1}{2}$	$27\frac{1}{2}$	Straight
1 *c*	96	,,	,,	,,	,,	,,	,,	$3\frac{31}{32}$	,,	$1\frac{1}{4}$	$1\frac{1}{4}$	,,	,,	Curves
2	95	,,	7	,,	,,	,,	$\frac{11}{16}$	$3\frac{9}{16}$	$1\frac{15}{16}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$22\frac{1}{2}$	27	Straight
2 *c*	101	,,	,,	,,	,,	,,	,,	$4\frac{1}{32}$	,,	$1\frac{1}{4}$	$1\frac{1}{4}$	,,	,,	Curves
3	100	,,	,,	$\frac{7}{16}$	$\frac{1}{2}$	,,	,,	$3\frac{11}{16}$	2	$1\frac{1}{8}$	$1\frac{1}{8}$	$22\frac{1}{2}$	$26\frac{1}{2}$	Straight
3 *c*	106	,,	,,	,,	,,	,,	,,	$4\frac{3}{32}$	,,	$1\frac{1}{4}$	$1\frac{1}{4}$	,,	,,	Curves
4	105	7	,,	,,	,,	,,	,,	$3\frac{13}{16}$	$2\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	26	$30\frac{1}{2}$	Straight
4 *c*	111	,,	,,	,,	,,	,,	,,	$4\frac{7}{32}$	,,	$1\frac{1}{4}$	$1\frac{1}{4}$	,,	,,	Curves
5	110	,,	,,	$\frac{29}{64}$	$\frac{33}{64}$	$\frac{5}{16}$	$\frac{23}{32}$	$3\frac{31}{32}$	$2\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{8}$	26	$30\frac{1}{2}$	Straight
5 *c*	116	,,	,,	,,	,,	,,	,,	$4\frac{13}{32}$	,,	$1\frac{1}{4}$	$1\frac{1}{4}$	,,	,,	Curves

* This is the dimension *D* in Fig. 55.

necessary to sacrifice conductivity to a small extent in order to gain hardness. The steel, whose chemical composition is given above, contains considerable carbon and manganese, and is comparatively hard. The conductivity varies from $\frac{1}{11}$ to $\frac{1}{13}$ of the conductivity of copper.

Fish plates should conform to the template recommended by the Engineering Standards Committee, and "shall be quite straight and smooth on all bearing surfaces, free from twists, cracks, blisters, flaws, or other defects, and shall have all fins and burrs carefully removed. The accuracy of fit between the rails and the fish plates is to be regarded as a matter of special importance, and sample rails shall be joined together at the works whenever the engineer or inspector desires to test the fitting of the fish plates." The weights of the inner and outer fish plates for the various "BS" sections are given in Table 1. Each plate is 24 ins. long, with six holes in it. The holes are $1\frac{1}{8}$ in. square in the outer plate, and $1\frac{1}{8}$ in. diameter in the inner plate.

The concrete bed. The rails are generally laid on a bed of concrete, which is 6 inches deep and extends for at least 18 inches beyond the track on both sides. This method presupposes a suitable foundation on which to lay the concrete; and unless this is present trouble will certainly occur, due to cracks and subsidences.

Although the concrete bed for tramway rails is practically a standard in Great Britain, it is interesting to note that wooden sleepers are largely used both on the Continent and in the United States of America. It appears that at Hull* the longitudinal wooden stringer on which the rails are placed is proving successful, and it is known that wooden sleepers last well when placed underground. It has been suggested that troubles due to rail joints might be lessened if the wooden bed were adopted on account of its being possessed of greater resilience than concrete.

In a paper entitled "Notes on Permanent Way for Tramways†," Mr A. N. Connett gives some valuable information on the subject of concrete. He points out that slow setting cement might be used with advantage if the roadway could be kept closed for a long enough period. The conditions under which tramways are laid preclude this, and a quick setting cement is used. He criticises the usual specification for a good concrete. "Six to one" concrete is often described as "four parts of broken stone, two parts of sand and one part of cement." Ballast or pit gravel, if suitable, is often allowed to be used instead of the mixture of broken stone and sand, and a mixture of "six of gravel to one of cement" is considered equivalent to the mixture of "four of

* See *Tramway and Railway World*, Jan. 12, 1905.
† See *The Electrician*, Nov. 4, 1904.

stone and two of sand and one of cement." It is obvious since the quantities are measured by volume that broken stone mixture will be richer in cement and will be the better of the two.

There are different ways of laying the rails. One method is to lay the concrete first, leaving the upper surface slightly below the level of the underneath side of the rails, afterwards grouting in with finer concrete when the rails have been placed in position on temporary wedges. This method has the disadvantage that the level of the concrete bed may accidentally be too high, in which case the layer for grouting in becomes thin and is liable to crack and crumble during service. Another method is to block up the rails and place the whole of the concrete in at one operation, carrying it well over the rail base at each side.

The British standard specification for Portland cement, December 1904, gives information as to the preparation and testing of this important material.

Paving is usually either granite or wood. The rails are connected at intervals of 7 ft. 6 ins. by tie bars, which pass through holes 3 ins. long by 1 in., being so shaped in order that the actual position of the bar may be suited to the junction between the setts or blocks. Figure 56 is a section of a typical tramway. The concrete bed rises to a level which leaves about 1 in. between it and the setts or blocks. A floating of cement upon which the blocks are placed is then provided. In the case of wood blocks, which usually measure 9" × 3" × 4", either creosoted deal or hard wood is employed. The hard wood is more expensive but lasts longer. Whether wood or granite be employed, molten pitch can be poured over the surface and into the joints. In the case of granite setts a three to one sand and cement mixture is sometimes poured over the setts and grouted in.

Rail joints. Considerable discussion has taken place with regard to the advisability of reinforcing in some way the ordinary fish plates for the purpose of making the rails as strong at the joints as elsewhere.

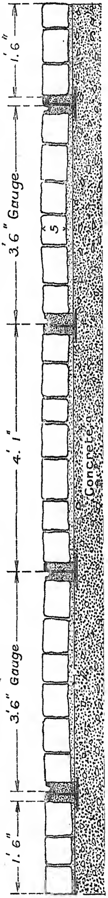


FIG. 56. Section of typical tramway track.

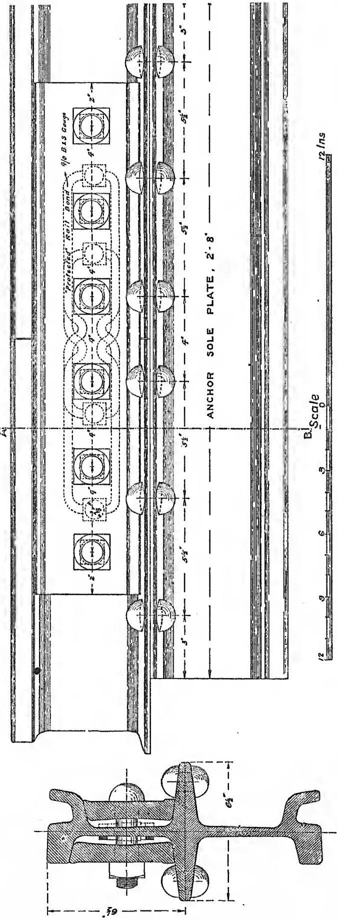


FIG. 57. Side elevation and cross section of Cooper and Smith's Anchor sole plate.

The chief cause of trouble in the track is the continual hammering of the cars as they pass these points. When the track is new the rail surface (except at crossings) is practically continuous; but as soon as the smallest wear occurs, there is a slight shock whenever a wheel passes from one rail to the next. The conditions of road paving render it impossible to tighten the fish bolts frequently, and in consequence the wear continually increases.

Various proposals have been made to meet this trouble. Messrs Cooper and Smith have introduced their Anchor sole plate, which is illustrated in figure 57, and which consists of a short length of ordinary tramway rail inverted and embedded in the concrete immediately under the rail joint, the flanges of the track rails and the inverted rail being riveted together. Engineers are by no means agreed on the merits of this system, one objection that is urged against it being that as soon as the smallest wear begins the shocks are transmitted to the narrow lower surface of the inverted rail which bears on the concrete. It is objected that this bearing surface is too narrow, and after a time the concrete begins to disintegrate under it.

To meet this objection the Winby Anchor chairs have been brought out. These chairs consist of a short length of wide-flanged H iron, laid in the concrete transversely under the rail joint. The abutting rails rest on the upper flange, which is provided with clips for gripping the rails. Wooden wedges or set screws must be inserted into the clips to hold the rails, and it is possible that a wooden wedge may be tight between one rail flange and the clip and not between the clip and the flange of the other rail.

The great point in designing rail joint appliances is to prevent any movement whatever, as such movement is always cumulative unless the joint is genuinely elastic as on ordinary surface railways. Possibility of slight movement means possibility for the entrance of water, and some engineers prefer to surround the whole joint up to the surface with a waterproof coating such as pitch. It cannot be said yet, however, that any system has been devised which is universally satisfactory. Figure 58 illustrates the Winby Anchor chair.

Anchor plates are sometimes inserted in the concrete between joints so as to anchor the whole rail and provide a really rigid construction. This is no doubt rather expensive, but if it prolongs the life of the track it is certainly justified.

The Continuous Rail Joint Company make a special type of fish plate which bends over the flange at the bottom of the girder and thus keeps the rail ends in alignment. This type of joint is in use on the Continent and is shewn in figure 68.

Substitutes for fish plates. At the present time there are three well-tried methods, whereby fish plates (and "bonds") can be dispensed with. The **Falk** cast welding process is much used in the United States of America, and consists in first cleaning the ends of the rails to be jointed by a sand-blast, second surrounding the ends by an iron mould, and third pouring in molten cast iron, which when solidified effectively joins the rails together, and at the same time establishes an effective connection through which the electric current can pass. The molten metal on coming into contact with the mould is cooled on the outside first and ultimately compresses the rest of the metal to such an extent as to force the cast iron and steel rail into most intimate contact. The joint thus made keeps the rails in alignment and secures the rail firmly in the concrete foundation. The electric welding process is exploited by the **Lorain** Steel Company and welds the rails together. The current from the 500 volt system drives a rotary converter, which through a suitable transformer produces a

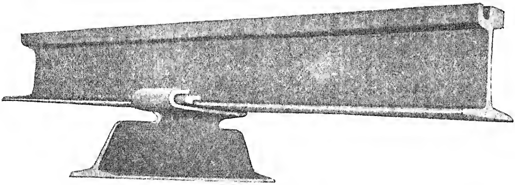


FIG. 58. Winby Anchor Chair.

current of sufficient magnitude to raise the rails to a welding temperature. It has been tried in the United Kingdom. Another method which has been tried in the United Kingdom with success is the **Thermit** process. It is well known that if iron oxide and aluminium in a finely divided state be raised to a sufficient temperature, so great is the affinity of the aluminium for oxygen that combination takes place and gives rise to such an intense heat that welding can be accomplished.

Special work. Electrical traction has necessitated the introduction of a steel for tramway points and crossings which will stand much greater wear and tear than that ordinarily used. The reason may be attributed to the increased weight of the electric cars, the greater proportion of non-spring-borne load, and the fact that the wheels being drivers there is a grinding action at points and crossings. Mr R. A. Hadfield some years ago introduced a manganese steel,

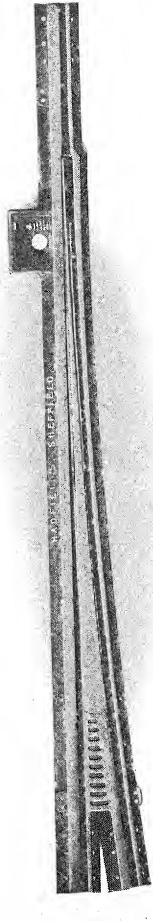


FIG. 59. Manganese steel point.

containing about 13 per cent. Mn and 1·25 per cent. C, which is extremely tough and yet so hard that it is practically impossible to machine it except by grinding. For points, crossings and in some cases for rails which are exposed to severe service, this steel is now being largely introduced and has successfully withstood the test of time. The first cost is about 15 to 20 per cent. more than that of the ordinary steel. Messrs Hadfield, Messrs Edgar Allen and other firms are now specialising in this class of work.

Tramway points are known by the terms "trailing" or "facing" according as the tracks converge or diverge in the direction of motion of the car. For facing and trailing points there are two classes in use, viz. "open" and "moveable." In the former the tongue is fixed and occupies a central position, whereas in the latter the tongue can be moved from side to side.

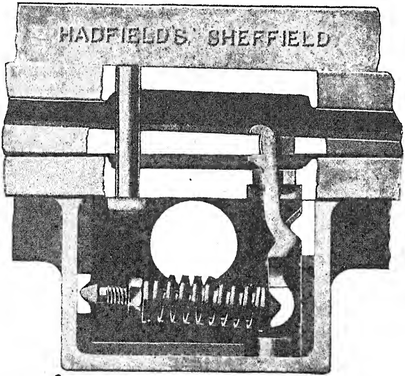


FIG. 60. Moveable point attachment for automatic working.

In the case of electric tramways "facing" points are frequently both moveable, but sometimes one is open and the other moveable. Two open points are only used when they are trailing. When moveable the tongue may be either operated by a lever, or it may be pressed to one side or the other against the force of a spring, by the inside surface of the flange of the wheel.

Figure 59 gives details of a typical point which can be either a pushing or pulling point. In the figure it is shewn as a pulling point

that is to say the spring pulls the tongue towards the straight side. A simple alteration can make the spring push the point from the straight side, whereas for automatic working, that is when it is required that the point should be kept hard up against one side or the

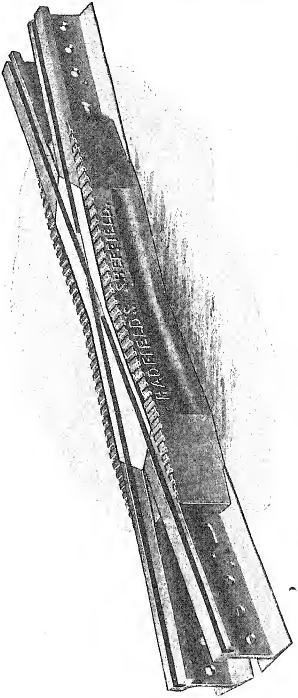


FIG. 61. Iron bound crossing with renewable manganese steel centre.

other, after being pressed over, the arrangement shewn in figure 60 can be employed. According to this the spring presses a small lever, which moves with the tongue, against the side of the box. The advantage of this arrangement is that it is extremely difficult to get

the tongue to stop in a central position. In some cases arrangements are made to operate the point or points by a removeable bar which is passed through a slot at the side of the track and actuates a transverse horizontal lever.

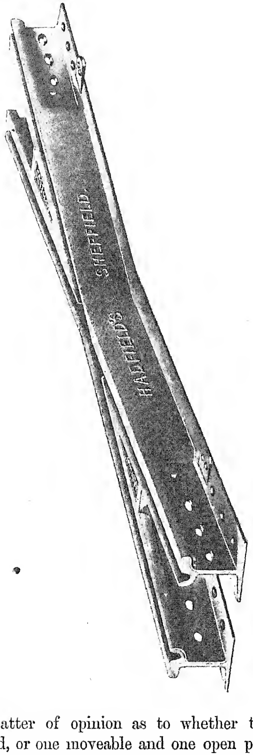


FIG. 62. Solid manganese steel crossing.

It is a matter of opinion as to whether two moveable points should be used, or one moveable and one open point. Both methods are adopted in practice.

Tramway crossings. A form of crossing largely used at the present time is shewn in figure 61. It consists of four ordinary steel rails consolidated with cast iron, which forms a convenient support for the manganese steel insert pieces. The method of fixing the insert is to place it in position supporting it free from the cast iron box, by aid of small steel distance pieces and cotters. The space in and around the insert is then filled in with spelter. Experience has however shewn that it is preferable to make the whole crossing in solid manganese steel, the reason being that the steel rails wear slightly at the place where they join the insert. The new piece has therefore to be lower on the surface than the original and consequently the full advantage is not gained, moreover it is not easy to get out the old insert. The introduction of the solid casting throughout is a distinct advantage, as the fish plates are supplied by the makers, and toggled to take account of the web of the casting being thicker than that of the abutting rail. A solid manganese steel crossing with extended legs, but without renewable pieces, is shewn in figure 62. In order to make a good finish of the running surface at the joints of the rails and manganese castings a petrol driven grinder has been successfully introduced by Messrs Hadfield. It has the advantage that the track can be completed before the electric current from the overhead wire or third rail is available; even when the line is in operation it is found more convenient to use than an electrically operated grinder.

Cross-over roads are provided in the case of double track construction in order that cars may cross over from one track to the other if necessary. There are usually two or three to the mile.

Turn-outs. When cars run in both directions along a single track it is necessary to provide passing places or "turn-outs" which consist of short lengths of double track. Turn-outs are of two kinds, equilateral and lateral, as illustrated in figures 73 and 75. In the former the track at both ends diverges from the straight, whereas in the latter a car entering the turn-out travels in a straight line until it reaches the end of the turn-out and then is diverted into the other track. In the former the amount of divergence from the straight is less than in the latter, but the latter has the advantage that there is no divergence at the facing points.

Interlaced tracks. Occasionally double tracks have to be so much compressed that they overlap; in this case the tracks are said to be "interlaced." It is obvious that cars cannot pass each other at such a place, and this is in reality the converse of a turn-out on a single track line.

Drain boxes. A detail of some importance is the drainage of water which runs along the groove of the rails. Especially is this the

case on inclines as the water carries down dirt and grit which ultimately gets into the points and crossings and causes undue friction. Drain boxes are provided and are bolted to the rail above the point when on an incline, and at any lowest point of a depression. On the level they are spaced out at intervals varying from 200 to 300 yards.

Examples of use of special work. Figures 63 and 64 shew where special parts would be inserted at a single and double turn-out.

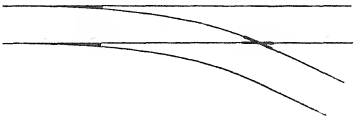


FIG. 63. Diagram of special work.

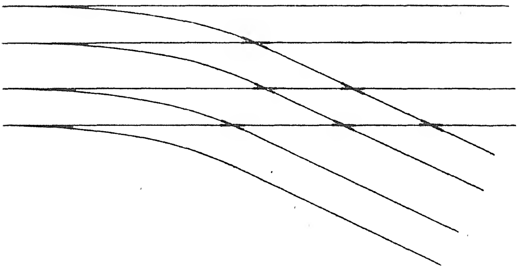


FIG. 64. Diagram of special work.

In the former three and in the latter ten special pieces would be required. Figure 65 is an example of special work at Sheffield which is wholly built up of manganese steel. In the case of complicated work the parts are always fitted together by the makers before delivery. Another very good example of special work is shewn in figure 163, in connection with the entrance to a car shed.

Setting out special work. At the end of this chapter is given a set of tables prepared by Messrs Hadfield's Steel Foundry Company for turn-outs and cross-over roads, giving full information as to the space occupied by such special work for different angles of crossing and different radii.

Curves. The radii of the curves on tramways naturally influence the use of cars having ordinary under-trucks or bogies. It has been seen that for curves of less than 150 feet radius the groove is $1\frac{1}{4}$ in. wide, but in the case of heavy traffic on sharp curves renewable rail checks have been adopted. A wheel base of 5 ft. 6 in. to 6 ft. 6 in.

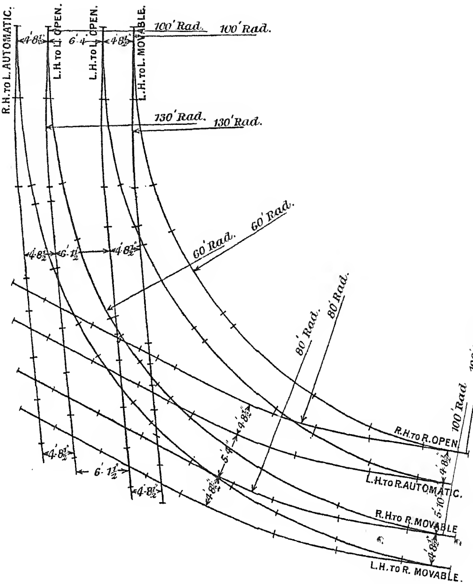


FIG. 65. Special work at Fitzalan Square, Sheffield. (Hadfield.)

is met with in practice on under-trucks, and the minimum radius is variously stated at from 30 to 60 feet. Tables 7 and 8, p. 115, shew how transition curves are constructed by Messrs Hadfield's Steel Foundry Company. These tables may be of use to engineers in setting out special work of all kinds.

Gauge. The point in the rail section from which to measure the gauge is indicated in figure 55. The gauge varies very much on tramways. When plenty of width of road is available 4 ft. $8\frac{1}{2}$ ins. is generally adopted. The metre gauge is common on the Continent.

There are, however, several systems in the British Isles on which the gauge is peculiar. Thus for instance at Belfast the gauge is 4 ft. 9 ins., at Blackburn and Bradford 4 ft., Greenock and Port Glasgow and others 4 ft. $7\frac{3}{4}$ ins.; many systems have 3 ft. 6 ins. and many others 3 ft. 0 in.

Gradients. In numerous cases severe gradients are met with, for example 1 in 10 and very occasionally 1 in 8. These have an influence upon the life of the rails, as it is found that the down rails wear considerably more than would be the case on the level.

Clearance. The Board of Trade require a minimum distance of 1 ft. 3 ins. between cars when passing round curves, or between the side of any car and the kerb, or any standing work such as lamp posts, etc. (see p. 436).

This regulation involves spreading the track on a double line to an extent depending on the sharpness of the curves. Table 2 gives the amount of spreading for various curves for two types of cars.

TABLE 2. *Variation of distance between centre lines of two tracks for different curves, and minimum width of roadway at a right angle bend.*

(*a*) Four wheel car 6′ 6″ width, 26′ 0″ effective length, 6′ 0″ wheel base.

Radius of centre line of smaller curve—feet	Distance between centre lines of tracks	Minimum road width	
		Single track	Double track
35	9′ 11″	19′ 2″	29′ 1″
40	9′ 9″	20′ 5″	30′ 2″
45	9′ 6″	21′ 8″	31′ 2″
50	9′ 3″	22′ 10″	32′ 1″
60	9′ 0″	25′ 9″	34′ 9″
75	8′ 9″	28′ 9″	37′ 6″
100	8′ 6″	36′ 5″	45′ 1″
150	8′ 4″	51′ 3″	59 7″
250	8′ 2″		
500	7′ 11″		
1000	7′ 10″		
infinity	7′ 9″		

(b) Double bogie car 7′ 0″ width, 32′ 0″ effective length, 12′ 0″ between bogie pins.

Radius of centre line of smaller curve—feet	Distance between centre lines of tracks	Minimum road width	
		Single track	Double track
35	11′ 5″	20′ 7″	32′ 0″
40	11′ 1″	21′ 8″	32′ 9″
45	10′ 9″	22′ 11″	33′ 8″
50	10′ 6″	24′ 2″	34′ 8″
60	10′ 2″	26′ 9″	36′ 11″
75	9′ 10″	30′ 9″	40′ 7″
100	9′ 5″	37′ 8″	47′ 1″
150	9′ 1″	52′ 0″	61′ 0″
250	8′ 9″		
500	8′ 4″		
infinity	8′ 3″		

In this table the columns under the heading "minimum road width" are for a right angle turn when the two roads are of the same width. Thus, for instance, if two roads meet at right angles, the width of each being 25 feet, single track only round the bend is possible, and the table shews that for a four wheel car the radius of the curve will be about 58 feet, and for a double bogie car about 54 feet.

In many cases, two roads meeting at an angle are unequal in width, in which case the above figures would require modification.

The rails as electrical conductors. On the score of simplicity and economy it is usual to utilise the track as part of the electrical circuit between the power house and the car. The rails in themselves are well fitted for this, being of considerable cross-section; but they are not continuous, and the ordinary joints with fish plates are very inefficient.

At first, before experience was gained, the drop of potential at the joints was somewhat neglected. The result of this was that a large proportion of the current passed from the rails to the earth, and thence to the power house. This was objectionable, as being the cause of corrosion in water pipes, etc., due to electrolysis, and led to many disputes between the owners of the water pipes and the tramway authorities.

The Board of Trade in this country, therefore, stepped in and laid down regulations to which all electric tramways were required to conform, limiting the permissible drop of volts in the rail return. It is obvious that if the track is made a sufficiently good conductor, that portion of the current which returns by the earth may be made as small as is desired.

Put briefly, the Regulations limit the difference of potential between any two points of the earth return to 7 volts, and the current density in any rail to a maximum of 9 amperes per square inch. These regulations together with others designed to safeguard the interests of private owners of pipes are set out in full in the Appendix at the end of this volume.

Bonding. To meet these regulations, the chief necessity was to eliminate the drop of volts at the joints. For this purpose copper bonds were devised, which should bridge the gap, and make good connection with the rails on each side.

Bonds usually consist of two parts (*a*) the two terminals, (*b*) the body, or part connecting the terminals.

The terminals consist of small copper cylinders which are expanded into the rail, either in the web or in the flange.

The part connecting the terminals may be either a copper rod, or may be made of a large number of fine wires all welded together into the heads of the terminals. The latter form is used when flexibility is desirable, *i.e.* when the body is short and subject to bending;

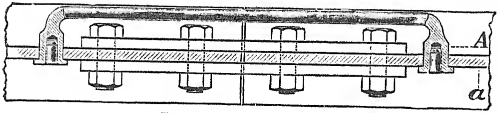


FIG. 66. Chicago rail bond.

the former is generally used outside the fish plates, or for cross-bonding the two rails. In the **Chicago** type of bond, an illustration of which is given in figure 66, the terminal *A* is expanded into the rail web *a* by means of a drift-pin which is driven into a conical hole in the terminal.

It will be noticed that the drift-pin is inserted from the opposite side of the rail to that of the bond. This is a drawback when a track already laid has to be bonded, as the ground has to be opened up on either side of the rail. The **Crown and Neptune** bonds get over this difficulty, and resemble the Chicago bond in that a drift-pin is used to expand the copper lug in the web of the rail. The pin is driven in from the same side as the bond. The **Columbia** bond is illustrated in figure 67 and is supplied at each end with a copper thimble which acts as a wedge between the web of the rail and the head of the bond. The head of the bond is tapered and inserted from the opposite side of the rail to that of the thimble. A press is then used to drive in the thimble between the web and the bond, thereby making a good joint.

On the Continent a simple and effective type of bond is employed and consists of two copper strips cut off to suit the particular joint which has to be made, and wedged into the rail web between a pair of half-round copper plugs and a steel wedge. Figure 68 illustrates two types of this bond; in the upper sketch the copper strips are outside the fish plates, and in the lower sketch between the fish plate and the web of the rail. In the former case the two strips are bent down and

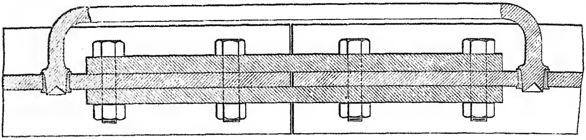


FIG. 67. Columbia rail bond.

lie along close to the bottom flange of the rail, whereas in the latter case the strips are cut longitudinally and spread so as to pass the fish bolts. In both cases the terminals are outside the fish plates. The method of bonding is to cut out suitable lengths of strip and insert them into the holes in the web together with the half-round copper plugs; the steel wedge is then driven in from the opposite side of the rail and the two ends of the strips folded over the end of the wedge to keep it in place.

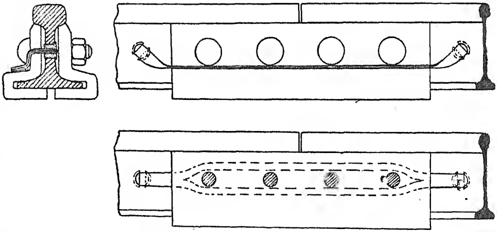


FIG. 68. Continental strip rail bond.

The **Edison-Brown** plastic bond makes use either of the fish plate itself or of a piece of copper sheet placed between the web and the fish plate as the intermediate conductor. The junction between the webs of the abutting rails and the intermediate conductor is effected by means of an amalgam. This amalgam or plastic metal is held in position between the contact surfaces by a block

of cork with a hole through the centre. The contact surfaces are thoroughly cleaned and treated with a solid alloy which silvers them and keeps them free from rust.

The "**Protected**" rail bond is made by fusing terminals of solid copper upon a loop of flattened copper wire. The terminals are then made to an exact size by re-heating and drop-forging. By the use of screw or hydraulic compressors the terminals may be "upset" so as to completely fill the hole in the web of the rail, even though it may have been reamered out an eighth of an inch larger than the bond terminal. Figure 69 shews two 7 inch girder rails double bonded with two "G 3"

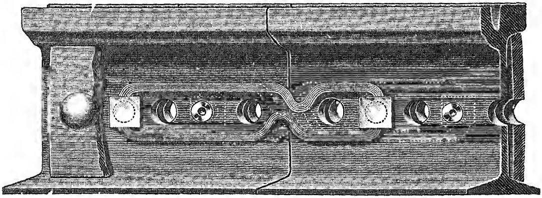


FIG. 69. Protected rail bond. (Forest City Electric Co.)

type protected bonds, the bond on the far side of the webs being indicated by dotted lines. This type is designed for double bonding when there is insufficient depth for two bonds placed one above the other, on the same side of the rails. The numbers following the letter of the type of bond shew the kind of wire used—of which there are six standard sizes. The No. 3 size has the dimensions ·193 in. × ·036 in. and requires the head of the terminal to be $\frac{1}{4}$ in. thick—that is to say this bond can be placed between the fish plate and web of the rail when the space is $\frac{1}{4}$ in. Table 3 gives a few particulars of these

TABLE 3. *Particulars of "Protected" rail bonds.*

Cross-section equivalent to B. and S. gauge	Number of strands	Outside dimensions of strands of No. 3 flatwise	Approximate weight of bond 12 in. long, $\frac{3}{4}$ in. terminals lbs.	Weight of conductor per foot—lbs.
0000	24	$\frac{7}{8}$ in. × $\frac{3}{16}$ in.	1·01	·645
000	19	$\frac{11}{16}$ in. × $\frac{3}{16}$ in.	·87	·513
00	15	$\frac{9}{16}$ in. × $\frac{3}{16}$ in.	·63	·406
0	12	$\frac{7}{16}$ in. × $\frac{3}{16}$ in.	·53	·322

bonds, which are generally supplied with either $\frac{3}{4}$ in. or $\frac{7}{8}$ in. diameter terminals.

Cross-bonding and bonding at special work. In addition to the bonds which join the successive lengths of rails together, it is considered good practice to cross-bond the two rails of a single track at intervals of about 40 yards, and in the case of double track to cross-bond the two tracks at intervals of about 100 yards.

It appears that most of the trouble with bonds occurs at bridges, steam or electric railway crossings, and turn-outs. The Forest City Electric Company recommend the systems of bonding shewn in figures 70 and 71, in the case of railway crossings and turn-outs.

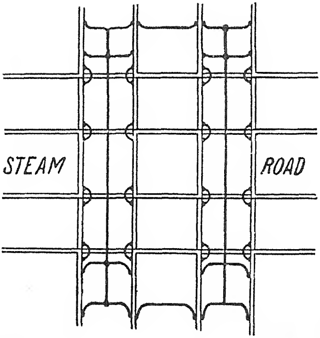


FIG. 70. Method of bonding at a tramway and steam railway crossing. (Forest City Electric Co.)

It will be seen that a cable of sufficient capacity to carry the whole current is carried across the railway, and it is advisable to place it in a boxing of asphalte to protect it from the possibility of damage due to electrolysis.

General remarks on bonding. The linear expansion of copper is about 50 per cent. greater than that of steel, and consequently if bonding is carried out in hot weather there is a liability for the contact between the web of the rail and the bond terminal to become loose in cold weather.

For example take the case of a $\frac{3}{4}$ inch terminal; for a fall of temperature of 50° C. the diameters would fall to $\frac{3}{4}$ $(1 - \cdot000012 \times 50)$

for iron rail and $\frac{3}{4}(1-\cdot000018\times50)$ for the copper terminal, disregarding elasticity, *i.e.* the difference in diameter is $\frac{3}{4}(\cdot000006\times50)$ inch or there would be a radial clearance of $\frac{3}{4}\times\cdot0003$ inch. This is extremely small but not negligible. To overcome this tendency bonds are fixed in place with considerable elastic stress, enough to ensure good contact under all conditions.

The protected rail bonds are generally fastened in by a hydraulic riveter which applies a pressure to a $\frac{7}{8}''$ terminal of about 25 tons. This type seems to possess an advantage over those which are fixed with a steel pin, in that the pressure applied is independent of the exact size of the various holes.

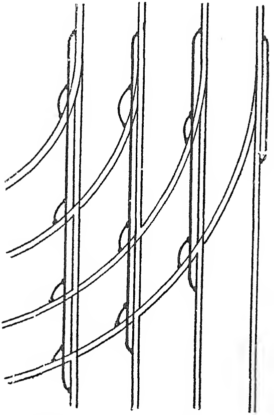


FIG. 71. Method of bonding at a double track junction. (Forest City Electric Co.)

Several points in connection with copper bonds are mentioned by C. H. Sturdevant* as follows:

It is very important to make sure that the rail hole is properly clean; a film of oxide may increase the contact resistance 160 times; a thin film of oil or white lead may increase it up to 60 per cent. Moisture in the hole is not very important at first, but leads to a gradual deterioration due to corrosion.

* *Street Railway Review*, London, Jan. 15, 1904.

Bonds should be proportioned so that the current density in the contact surface should not exceed 90 to 100 amperes per sq. in.; and the current density in the body of the bond should not be greater than 1200 amperes per square inch. The usual practice is to bond tramway rails weighing about 100 lbs. per yard with two 0000 B. and S. bonds per joint.

A $\frac{7}{8}$ inch terminal in a $\frac{1}{2}$ inch rail should give a contact resistance as low as $2{\cdot}3 \times 10^{-6}$ ohms; this may be taken as a minimum.

Electrically controlled points. In congested parts of large tramway systems when sometimes as many as 100 cars may pass through per hour, it has been usual to employ pointsmen to operate the points. Electrically operated points are now being tried on certain systems with a view to economy in working. The methods at present employed make use of either an electric motor, as in Parr's controller,

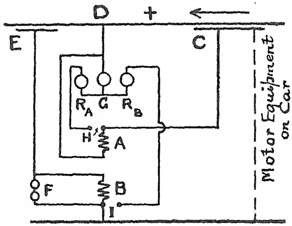


FIG. 72. Diagram of connections of Tierney and Malone electric point shifter.

or a solenoid as in Turner's or Tierney and Malone's controller. All of the methods are applicable to either the overhead or conduit systems. In Parr's and Turner's point shifters the motors and solenoids respectively are at the side of the track. Tierney and Malone place their solenoids underground, one on either side of the point to be operated.

Space does not permit of these systems being illustrated in detail, but the following description of Tierney and Malone's system will make the operation clear. In figure 72 D is the overhead conductor or positive conductor in the case of a conduit system. A and B are the coils of two solenoids whose plungers operate on each side of the point to move it to and fro. Suppose the car is approaching the point in the direction indicated by the arrow and that it is about 50 or 60 feet away. The driver can see if the point is in the right position either by looking at the point itself or the signal lamps. As the car approaches the point, the trolley wheel or contact shoe runs on to the contact C which is insulated from the positive main. The conductor keeps his

controller on one of the notches, say the first one. A current can then flow from the point D through the solenoid A to the contact C and thence via the motor equipment to the negative pole of the system. The plunger of the solenoid is then drawn over and operates the point. The point there remains until the second contact E is reached, and this is not until the car has passed the point. The contact E is so constructed that the trolley wheel presses it into contact with the overhead wire, or the shoe in a conduit system touches both it and the positive conductor. A current can then flow from E through the solenoid B and resets the point. The lamps F are for the purpose of preventing any serious arc due to the self-induction of B. Three signal lamps R_a, G, R_b (red, green and red respectively) are placed in a conspicuous position, and the current through them is controlled by a double switch HI mechanically operated by the point in such manner that GR_b are left lighted. This indicates that the road to the right is blocked. When contact with C is made the lamps R_aG will light up if the point is operated. When it is desired to operate a point but not to reset it, as may be the case when trailer cars are used, since the distance

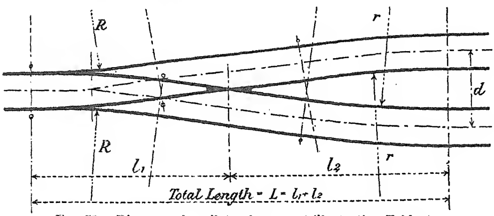


FIG. 73. Diagram of equilateral turn-out illustrating Table 4.

between C and E may not always be sufficient to allow of the cars getting past the point before it is reset, a switch of special construction is employed, and the second contact E is not used. The switch is operated by the tongue in such manner as to disconnect the solenoid, which has just been magnetised when the contact C was touched, after a predetermined interval of time (about 5 seconds) and to connect the other solenoid to the contact C in readiness for the next car if necessary, the interval of 5 seconds being considered sufficiently long to enable the car to clear contact C.

Tables for special track work*. The following tables give dimensions for various crossings and turn-outs in accordance with designs prepared by Messrs Hadfield's Steel Foundry Company.

* The authors are indebted to Messrs Hadfield for leave to publish these tables, which are taken from their list No. 21 for special track work. These tables are copyright and must not be reproduced without Messrs Hadfield's permission.

Table 4. *Particulars of standard equilateral turn-out; gauge* $4'\ 8\frac{1}{2}''$.
(See figure 73.)

Radius of points	Angle of crossing	Lead of crossing	Radius of plain end	Distance between centres		Variation in l_2 for every inch diff. of d
R	ϕ°	l_1	r	d	l_2	V
200′ 0″	1 in 5	33′·7372	200′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	26′·4264 28′·9237 31′·4210 33′·9184 36′·4157	4″·9946
200′ 0″	1 in $5\frac{1}{2}$	35′·1636	200′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	27′·1665 29′·9136 32′·6606 35′·4076 38′·1547	5″·4940
200′ 0″	1 in 6	36′·7520	200′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	28′·0615 31′·0596 34′·0577 37′·0558 40′·0539	5″·9961
200′ 0″	1 in 7	40′·2743	200′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	30′·1843 33′·6862 37′·1882 40′·6902 44′·1921	7″·0039
200′ 0″	1 in 8	43′·9962	200′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	32′·5378 36′·5300 40′·5221 44′·5143 48′·5065	7″·9843
300′ 0″	1 in 5	38′·7301	300′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	31′·4193 33′·9166 36′·4139 38′·9112 41′·4086	4″·9946
300′ 0″	1 in $5\frac{1}{2}$	39′·7045	300′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	31′·7075 34′·4545 37′·2016 39′·9486 42′·6956	5″·4940
300′ 0″	1 in 6	40′·9142	300′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	32′·2236 35′·2217 38′·2198 41′·2179 44′·2160	5″·9961
300′ 0″	1 in 7	43′·8392	300′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	33′·7492 37′·2511 40′·7531 44′·2551 47′·7570	7″·0039
300′ 0″	1 in 8	47′·1242	300′ 0″	8′ 0″ 8′ 6″ 9′ 0″ 9′ 6″ 10′ 0″	35′·6659 39′·6580 43′·6502 47′·6424 51′·6345	7″·9843

TABLE 5. *Particulars of standard cross-over; gauge* 4′ 8½″. (See figure 74.)

Radius of points	Angle of crossing	Lead of crossing	Distance between centres of tracks		Variation in l_2 for every inch diff. of d
R	$\phi°$	l_1	d	l_2	V
100′ 0″	1 in 4½	32′·5707	8′ 0″	25·7449	4″·4494
			8′ 6″	27·9696	
			9′ 0″	30·1943	
			9′ 6″	32·4190	
			10′ 0″	34·6437	
100′ 0″	1 in 5	33′·7626	8′ 0″	26·2866	4″·9445
			8′ 6″	28·7589	
			9′ 0″	31·2312	
			9′ 6″	33·7035	
			10′ 0″	36·1758	
100′ 0″	1 in 5½	35′·1827	8′ 0″	27·0355	5″·4485
			8′ 6″	29·7598	
			9′ 0″	32·4841	
			9′ 6″	35·2084	
			10′ 0′	37·9326	
100′ 0″	1 in 6	36′·7667	8′ 0″	27·9387	5″·9544
			8′ 6″	30·9160	
			9′ 0″	33·8932	
			9′ 6″	36·8705	
			10′ 0″	39·8477	
150′ 0″	1 in 4½	38′·1202	8′ 0″	31·2944	4″·4494
			8′ 6″	33·51916	
			9′ 0″	35·7438	
			9′ 6″	37·9685	
			10′ 0″	40·1932	
150′ 0″	1 in 5	38′·7680	8′ 0″	31·2920	4″·9445
			8′ 6″	33·7643	
			9′ 0″	36·2366	
			9′ 6″	38·7089	
			10′ 0″	41·1812	
150′ 0″	1 in 5½	39′·7330	8′ 0″	31·5859	5″·4485
			8′ 6″	34·3101	
			9′ 0″	37·0344	
			9′ 6″	39·7587	
			10′ 0″	42·4830	
150′ 0″	1 in 6	40′·9360	8′ 0″	32·1081	5″·9544
			8′ 6″	35·0853	
			9′ 0″	38·0625	
			9′ 6″	41·0398	
			10′ 0″	44·0170	

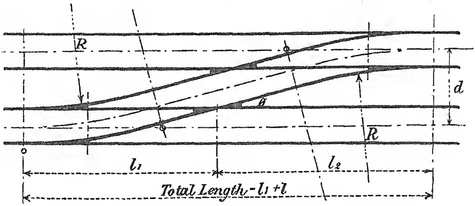


FIG. 74. Diagram of cross-over road illustrating Table 5.

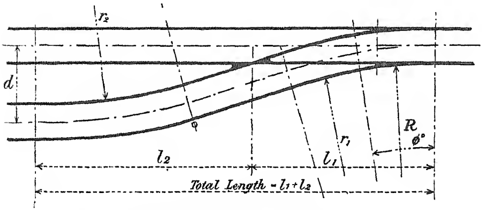


FIG. 75. Diagram of lateral turn-out illustrating Table 6.

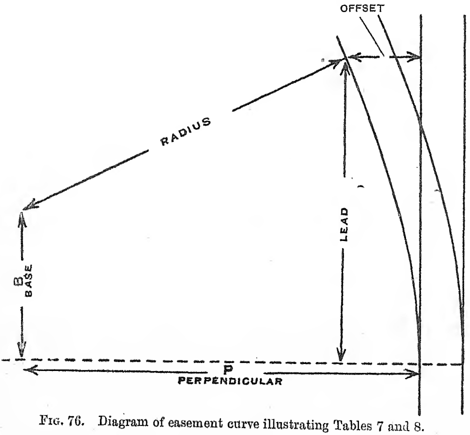


FIG. 76. Diagram of easement curve illustrating Tables 7 and 8.

TABLE 6. *Particulars of standard lateral turn-out; gauge* 4′ 8½″. (See figure 75.)

Radius of points	Angle of point radius	Secondary radius	Angle of crossing	Lead of crossing	Plain end radius	Distance between centres of tracks		Variation in l_2 for every inch diff. of d
R	ϕ°	r_1	θ	l_1	r_2	d	l_2	V
100′ 0″	7° 0′	200′ 0″	1 in 5	35′·2719	200′ 0″	8′ 0″	36·2973	4″·9445
						8′ 6″	38·7696	
						9′ 0″	41·2419	
						9′ 6″	43·7142	
						10′ 0″	46·1865	
100′ 0″	7° 0′	200′ 0″	1 in 5½	36′·1581	200′ 0″	8′ 0″	36·1362	5″·4485
						8′ 6″	38·8605	
						9′ 0″	41·5848	
						9′ 6″	44·3091	
						10′ 0″	47·0334	
100′ 0″	7° 0′	200′ 0″	1 in 6	37′·3569	200′ 0″	8′ 0″	36·2774	5″·9544
						8′ 6″	39·2546	
						9′ 0″	42·2319	
						9′ 6″	45·2091	
						10′ 0″	48·1863	
100′ 0″	7° 0′	200′ 0″	1 in 7	40′·4295	200′ 0″	8′ 0″	37·2147	6″·9682
						8′ 6″	40·6988	
						9′ 0″	44·1829	
						9′ 6″	47·6671	
						10′ 0″	51·1512	
150′ 0″	5° 30′	300′ 0″	1 in 5½	42′·7701	300′ 0″	8′ 0″	45·2369	5″·4485
						8′ 6″	47·9612	
						9′ 0″	50·6855	
						9′ 6″	53·4098	
						10′ 0″	56·1341	
150′ 0″	5° 30′	300′ 0″	1 in 6	43′·1793	300′ 0″	8′ 0″	44·6160	5″·9544
						8′ 6″	47·5933	
						9′ 0″	50·5705	
						9′ 6″	53·5478	
						10′ 0″	56·5250	
150′ 0″	5° 30′	300′ 0″	1 in 7	44′·9965	300′ 0″	8′ 0″	44·3536	6″·9682
						8′ 6″	47·8377	
						9′ 0″	51·3218	
						9′ 6″	54·8059	
						10′ 0″	58·2900	
150′ 0″	5° 30′	300′ 0″	1 in 8	47′·6422	300′ 0″	8′ 0″	44·9654	7″·9530
						8′ 6″	48·9419	
						9′ 0″	52·9184	
						9′ 6″	56·8949	
						10′ 0″	60·8714	

TABLE 7. *Particulars of Hadfield's standard Easement curve. Plain end spiral. From 330′ 6″ to 30′ 0″ radius.* (See figure 76.)

Inner radius	Deflection angles		Co-ordinates of centres		Lead	Offset
	Partial	Total	Base "B"	Perpendicular P.		
330′ 6″	0° 26′ 0″	0° 26′ 0″		330′·5000	2′·4995	·00945
186′ 9″	0° 46′ 0″	1° 12′ 0″	1′·0871	186′·7541	4′·9981	·04507
130′ 3″	1° 6′ 0″	2° 18′ 0″	2′·2704	130′·2665	7′·4975	·121431
100′ 0″	1° 26′ 0″	3° 44′ 0″	3′·4844	100′·0408	9′·9956	·25308
81′ 0″	1° 46′ 0″	5° 30′ 0″	4′·7215	81′·0812	12′·4850	·45410
68′ 3″	2° 6′ 0″	7° 36′ 0″	5′·9435	68′·3899	14′·9700	·73943
58′ 10″	2° 26′ 0″	10° 2′ 0″	7′·1890	59′·0559	17′·4389	1′·12230
51′ 9″	2° 46′ 0″	12° 48′ 0″	8′·4230	52′·0809	19′·8882	1′·6169
46′ 3″	3° 6′ 0″	15° 54′ 0″	9′·6415	46′·7176	22′·3122	2′·23718
41′ 9″	3° 26′ 0″	19° 20′ 0″	10′·8743	42′·3898	24′·6963	2′·99412
38′ 0″	3° 46′ 0″	23° 6′ 0″	12′·1158	38′·8512	27′·0247	3′·8980
35′ 0″	4° 6′ 0″	27° 12′ 0″	13′·2928	36′·0918	29′·2913	4′·9622
32′ 4″	4° 26′ 0″	31° 38′ 0″	14′·5117	33′·7200	31′·4704	6′·1907
30′ 0″			15′·7354	31′·7335		

TABLE 8. *Particulars of Hadfield's standard Easement curve. Point spiral. From 100′ 0″ to 30′ 0″ radius.* (See figure 76.)

Inner radius	Deflection angles		Co-ordinates of centres		Lead	Offset
	Partial	Total	Base "B"	Perpendicular P.		
100′ 0″	7° 25′ 0″	7° 25′ 0″		100′·0000	12′·9084	·83663
81′ 0″	1° 46′ 0″	9° 11′ 0″	2′·4525	81′·15895	15′·3797	1′·19716
68′ 3″	2° 6′ 0″	11° 17′ 0″	4′·4874	68′·57238	17′·8412	1′·64154
58′ 10″	2° 26′ 0″	13° 43′ 0″	6′·3298	59′·3377	20′·2804	2′·18269
51′ 9″	2° 46′ 0″	16° 29′ 0″	8′·00947	52′·45651	22′·6928	2′·8333
46′ 3″	3° 6′ 0″	19° 35′ 0″	9′·57002	47′·18254	25′·0719	3′·60787
41′ 9″	3° 26′ 0″	23° 1′ 0″	11′·07832	42′·94285	27′·4025	4′·51651
38′ 0″	3° 46′ 0″	26° 47′ 0″	12′·54457	39′·49138	29′·6680	5′·56813
35′ 0″	4° 6′ 0″	30° 53′ 0″	13′·89642	36′·81328	31′·8616	6′·77572
32′ 4″	4° 26′ 0″	35° 19′ 0″	15′·26517	34′·52472	33′·9567	8′·14172
30′ 0″			16′·61386	32′·62105		

CHAPTER 7.

TRAMWAY OVERHEAD EQUIPMENT, INCLUDING POLES.

The overhead line. The method which is most widely adopted of transmitting electrical energy to the car is that of the overhead line. This consists of a copper wire stretched at a suitable height above the track and supported at frequent intervals. Current is "collected" from this wire by the collector on the car.

The Catenary. A perfectly flexible, uniform wire suspended from two fixed points under the action of gravity hangs in a curve called the "catenary." This curve in general is an exponential curve; but for the case in which the dip or the "sag" is small compared to the distance between the fixed points or the "span" it is sufficiently accurate to assume that it is a parabola.

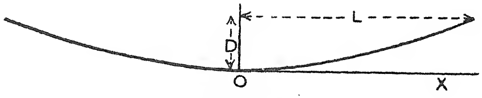


FIG. 77. Diagram of catenary curve.

Thus the equation of the curve may be written

$$y = \frac{1}{2}\frac{x^2}{c},$$

in which the origin is at the lowest point of the curve and c is a constant.

From this equation it is evident that if d be the sag, and $2l$ the span, when $x = l$, $y = d = \frac{l^2}{2c}$ (see figure 77).

The tension in the wire. Now it can be proved by taking moments round the point of support that T, the tension in the wire at its lowest point, is $c \times w$, where w is the weight of a unit length of the wire, and c the constant mentioned above.

Therefore the sag, the span and the tension in the wire are connected by the following equation,

$$d = \frac{l^2}{2\frac{T}{w}}.$$

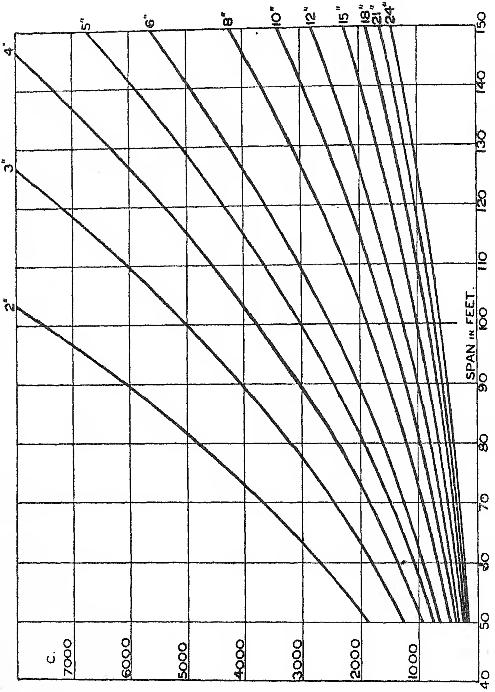


FIG. 78. Curves giving the relation between the span and the constant of the catenary for different values of the sag.

Figure 78 shews a number of curves giving the relation between the span and the constant c for different values of the sag.

As an example of the use of this sheet of curves, take the case of a

wire No. 00 L.S.G., the diameter of which is ·348 inch and the weight of which is ·365 lb. per foot, stretched between two points 120 ft. apart so that the sag is 9 inches.

From the curve for a sag of 9 inches it appears that the value of c corresponding to a 120 feet span is 2400. Therefore the tension in the wire will be

$$2400 \times \cdot 365 = 880 \text{ lbs.}$$

The effect of temperature. Speaking generally, the effect of a rise of temperature will be to increase the sag by causing an expansion of the wire, and conversely a fall of temperature will reduce the sag.

Now from the properties of the catenary the length of the wire between the points of support is $2s$ where

$$s = l + \frac{l^3}{6c^2}.$$

The effect of elasticity must be taken into account, and this is done as follows, in accordance with the approximate method given by Professor B. Hopkinson*.

The half length of the catenary is

$$l + \frac{l^3}{6c^2},$$

the tension in the wire $\qquad cw,$

therefore the extension in the half span is

$$\left(l + \frac{l^3}{6c^2}\right)\frac{cw}{a\mathsf{E}},$$

where a is the cross-section of the wire and E is Young's Modulus of Elasticity.

Hence the unstretched length is

$$\left(l + \frac{l^3}{6c^2}\right)\left(1 - \frac{cw}{a\mathsf{E}}\right) = l_0 \text{ say.}$$

Now suppose the temperature rises by t degrees the unstretched length will become $l_0(1 + \alpha t)$, where α is the coefficient of linear expansion.

In consequence of this rise of temperature the wire will take up a slightly different position,

$$\text{say } y = \frac{x^2}{2c'};$$

then the tension in the wire will become $c'w$, which causes an extension

$$l_0(1 + \alpha t)\frac{c'w}{a\mathsf{E}};$$

* *Electrician*, January 25, 1901. The authors believe that the solution of the equation in the form of a set of curves will be found the most useful.

that is to say the length of the catenary will become

$$l_0(1+at)+l_0(1+at)\frac{c'w}{a\mathsf{E}},$$

or
$$l_0(1+at)\left(1+\frac{c'w}{a\mathsf{E}}\right),$$

or
$$\left(l+\frac{l^3}{6c^2}\right)\left(1-\frac{cw}{a\mathsf{E}}\right)(1+at)\left(1+\frac{c'w}{a\mathsf{E}}\right),$$

and this will be equal to $l+\frac{l^3}{6c'^2}$.

Now all the terms $\frac{l^3}{6c^2}$, $\frac{cw}{a\mathsf{E}}$, at, and $\frac{c'w}{a\mathsf{E}}$ are small quantities; therefore neglecting the products of small quantities, the equation may be written thus:

$$l+\frac{l^3}{6c'^2}=l+\frac{l^3}{6c^2}+l\left(at+\frac{w}{a\mathsf{E}}[c'-c]\right),$$

or
$$\frac{l^2}{6}\left(\frac{1}{c'^2}-\frac{1}{c^2}\right)=at+\frac{w}{a\mathsf{E}}(c'-c).$$

From this equation a set of curves for any given value of l can be calculated, giving the relation between t and c. A set of curves for a span of 120 feet is given in figure 79, in which the following values have been taken:

$$a=\cdot 00001,\quad \frac{w}{a}=3\cdot 86,\quad \mathsf{E}=18{,}000{,}000 \text{ lbs. per sq. inch.}$$

An example of the use of these curves is as follows:

Suppose a No. 00 L.S.G. wire to be stretched with a sag of 9 inches in a 120 feet span at a temperature of 60° F.

Then at this temperature the value of c will be 2400. The point in the diagram corresponding to $c=2400$, $t=60$ lies on a certain curve. This particular curve will give the behaviour of the wire at any other temperature; thus by following the curve down to a temperature of 100° F. the corresponding value of c will be found to be 1400, and consequently the sag will be about 17 inches and the tension will be

$$1400\times\cdot 365=510 \text{ lbs.}$$

Erecting the wire. It is thus evident that the elasticity of the wire provides a convenient safeguard against breakages due to frost. For instance, in the example given above, the tension in the wire when the temperature is 10° F. (22° of frost) would be about

$$4400\times\cdot 365=1610 \text{ lbs.}$$

(which is about the elastic limit), whereas neglecting the effect of elastic extension a fall of temperature from 60° F. to about 10° F. would cause the wire to break.

Thus a reasonable figure to adopt for the erection of the trolley line is to allow a sag of about 9 inches at a temperature of 60° F., corresponding to a tension of about 880 lbs. in a No. 00 L.S.G. wire for a span of 120 feet.

Snow, ice and wind pressure. The above figures for allowable sag and stress in the trolley wire must be taken with caution. In some localities conditions are much more severe, due to the possibility of the wire becoming coated with ice and due to wind pressure.

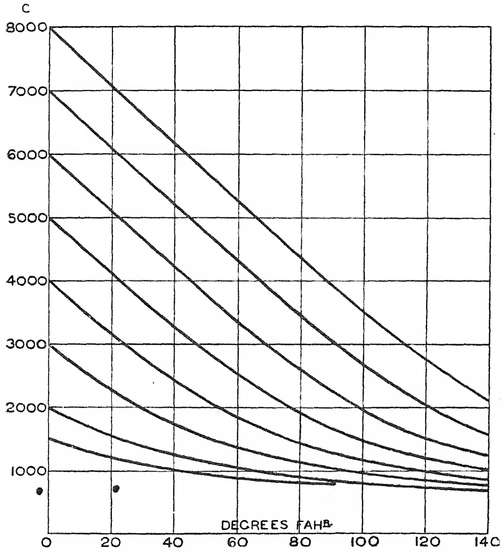


FIG. 79. Curves of the variation of the constant of the catenary due to temperature, for a span of 120 feet.

These conditions naturally vary a great deal from place to place, comparatively little trouble being experienced in this country. In America and on the Continent, weather conditions are occasionally such that it is a practical impossibility to prevent the lines coming down.

The worst case occurs when ice coating and wind pressure are simultaneous. Fortunately it seldom happens that the worst gales coincide with very low temperatures.

Cases are on record in which a No. 10 wire has been coated with ice to such a depth that the diameter was increased to 2 inches. This alone would generally be sufficient to bring the wire down.

Opinions vary considerably as to what allowances should be made. Dealing first with the wind, the pressure is variously stated* at ·005 to ·0025 × V^2 lbs. per sq. foot, V being the velocity in miles per hour. For lines near the ground there is no necessity to allow more than 30 lbs. per square foot, and where the line is protected by houses and trees 20 lbs. per square foot is sufficient. The standard practice for telegraph lines in this country is to allow for a wind pressure of 17·85 lbs. per square foot†.

As regards ice coatings it appears to be the standard practice in America to allow for a layer $\frac{1}{2}$ inch thick all over the wire, *i.e.* an increase of 1 inch in the diameter‡, coincident with a pressure of 20 to 25 lbs. per square foot, but such conditions would very rarely occur in this country. Perrine§ states that it is very rare for the ice coating to be more than $\frac{1}{8}$ inch thick.

For present purposes it should be sufficient to take this figure of $\frac{1}{8}$ inch, and a wind pressure of 20 lbs. per square foot, allowing for the pressure on a cylindrical surface as ·6 times that on a flat surface.

The pressure per foot run of wire will, therefore, be

$$20 \times \cdot 6 \times \frac{D}{12} = D,$$

that is, the pressure is equal to the diameter of the wire in inches.

Under these conditions, consider the case of the No. 00 L.S.G. trolley wire already examined.

Initial conditions, span 120 feet, sag 9 inches at 60° F.

Worst condition—$\frac{1}{8}$ inch ice coating, wind pressure 20 lbs. per square foot at 10° F.

* Dawson's *Electric Traction Pocket-Book* gives ·005V^2.

Langley in *Experiments on Aerodynamics* gives ·0036V^2 with a factor $\frac{2 \sin \alpha}{1 + \sin^2 \alpha}$ to allow for the angle of incidence.

Experiments on moving trains give a result ·00275V^2 (Aspinall, and Berlin-Zossen, etc.).

† See *Electrician*, September 18, 1885, p. 348.

‡ See Bell's *Electrical Power Transmission*, pp. 473, 474, also *Street Railway Journal*, March 24, 1906, p. 455.

§ *Conductors for Electrical Distribution*, Chapter 12.

Diameter of wire, uncoated	... ...	·348 inch
" coated	... ...	·6 inch say
Weight per foot of wire	... ...	·365 lb.
" of ice...	... ...	·075 lb.
Wind pressure per foot	... ...	·6 lb.

Total load per foot $\sqrt{\cdot 6^2 + (\cdot 44)^2} = \cdot 745$ lb.

In the equation for finding the sag at the low temperature

$$\frac{l^2}{6c'^2} = \frac{l^2}{6c^2} - \frac{cw}{a\mathrm{E}} + \alpha t + \frac{c'w'}{a\mathrm{E}},$$

$l=60$, $c=2400$, $w=\cdot 365$, $a=\cdot 095$, $\mathrm{E}=18{,}000{,}000$, $\alpha=\cdot 00001$, $t=-50$, $w'=\cdot 745$, c' is required; by substituting these values c' is found to be 2340,

i.e. the sag (obliquely) $= \frac{3600}{4680} \times 12$ inches $= 9\frac{1}{4}''$,

the tension in the wire $= 2340 \times \cdot 745 =$ **1740 lbs.,**

and the wire blows out sideways to an angle of about 55° with the vertical, so that the tension is very little increased by the action of wind and ice.

Trolley wire. The wire used for the trolley line is generally hard drawn copper. The following particulars will be useful:

Specific gravity, about	... ...	8·9
Weight of a cubic foot	... ...	555 lbs.
Breaking strain, about	... ...	23 to 26 tons per sq. in.
Elastic limit, about ...	... ...	$7\frac{1}{2}$ to $12\frac{1}{2}$ tons per sq. in.
Young's Modulus, about	... ...	18,000,000 lbs. per sq. in.
Electrical resistance ...	...	98 °/o Matthiessen's standard
Specific resistance at 0° C.	...	$1\cdot 65 \times 10^{-6}$ ohms per cub. cm.
" " at 60° F.	...	$1\cdot 75 \times 10^{-6}$ " "

The following table gives the various particulars for different sizes of wire, the breaking strain being calculated on a load of 23 tons per square inch.

TABLE 9. *Particulars of hard drawn copper wires.*

Size L.S.G.	Diameter		Section		Elastic limit lbs.	Breaking strain lbs.	Weight		Resistance, 60° F.	
	ins.	mm.	sq. in.	sq. mm.			per mile lbs.	per 100 yds. lbs.	per mile ohms	per 100 yds. ohms
00000	·432	10·97	·147	94·6	2470	7570	2980	169	·298	·0169
0000	·400	10·16	·126	81·1	2120	6500	2560	145	·347	·0198
000	·372	9·45	·109	70·1	1840	5600	2210	126	·400	·0227
00	·348	8·84	·095	61·3	1600	4900	1930	109	·460	·0262
0	·324	8·23	·082	53·2	1380	4220	1660	95	·533	·0303

The sizes in Table 9 include practically all those now in use; in 1904 out of 47 Corporations (three of which used two sizes) 14 used No. 0, 4 used No. 00, 15 used No. 000 and 17 used No. 0000*.

Figure 8 wire of equivalent section is sometimes used; but many engineers are of opinion that it is more difficult to erect, and it is liable to twist and kink.

Support of the trolley wire. The trolley wire has to be supported so that it follows approximately the line of the track. This alone involves a diversity of construction, different types being required on a straight track, on a curved track, at points, at crossings, under railway or other bridges, and over swing bridges.

Electrically, the trolley wire must be insulated from its supports, and means must be provided for sectionalising, that is for dividing the trolley wire into a number of sections that can be insulated from neighbouring sections. Further some form of guard must be provided to prevent telegraph and telephone wires falling on the trolley wire.

Overhead construction has become practically standardised for tramways, and is broadly of two types, viz. span wire and side bracket construction. In the former, the trolley wire is supported by means of insulated hangers attached to span wires fixed to poles at the sides of the street or to hooks fastened in the walls of the houses. In the latter type the insulated hanger is suspended from a side bracket attached to a single pole.

It is the universal practice to use double insulation, that is to provide two distinct sets of insulators in series between the trolley wire and the ground. This is effected by insulating the trolley wire from the span wire and the span wire from the pole or wall hook.

The following is a list of the various parts used in the overhead construction, illustrated in figures 80 to 91 †.

Ears are of various kinds, deep groove, shallow groove, splicing, single and double anchor, and feeder ears. These are for supporting the trolley wire, which is soldered into the groove. Sometimes they form mechanical clips, especially with figure 8 wire, the upper part of the wire being clamped into the groove. They are usually made of bronze or gun-metal, and vary in length according to circumstances from 6 inches to 36 inches. A suitable length for a No. 00 trolley wire on a straight run would be 18″. For heavier wire and for sharp curves longer ears would be necessary. The various types are shewn in figure 80.

* Tweedy and Dudgeon, *Electrician*, Feb. 23, 1906, p. 764.

† The authors are indebted to Messrs Estler Bros. and to Messrs Brecknell Munro and Rogers for most of these illustrations.

The use of mechanical clips and grooved or figure 8 wire is becoming more general for several reasons. In the first place, the wire may be tightened up by being drawn along, the clip being simply put on again in a fresh place; this operation would be more difficult with soldered ears of the old type. Again mechanical clips do not offer any obstruction to the smooth running of the trolley wheel, and the weakening of the copper wire by the process of soldering is avoided.

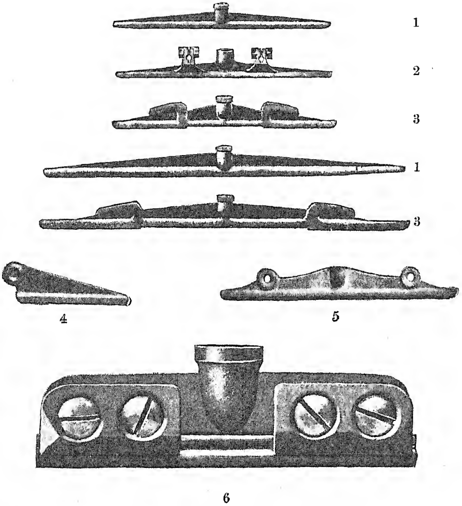


FIG. 80. Various types of ears.

1. Straight line ear.
2. Feeder ear.
3. Splicing ear.
4. Single ended anchor ear.
5. Double ended anchor ear.
6. Mechanical ear for figure 8 wire.

Insulated hangers. These consist of an insulated bolt which screws into the tapped hole of the ear, and a body and cap. The span wire engages with the body and thus supports the trolley wire. The bolt is made of steel or bronze, and the insulation is moulded on it. The insulation is of various kinds such as "Ambroin," "Verus," "Hecla," etc., and generally consists of a mixture of mica, asbestos,

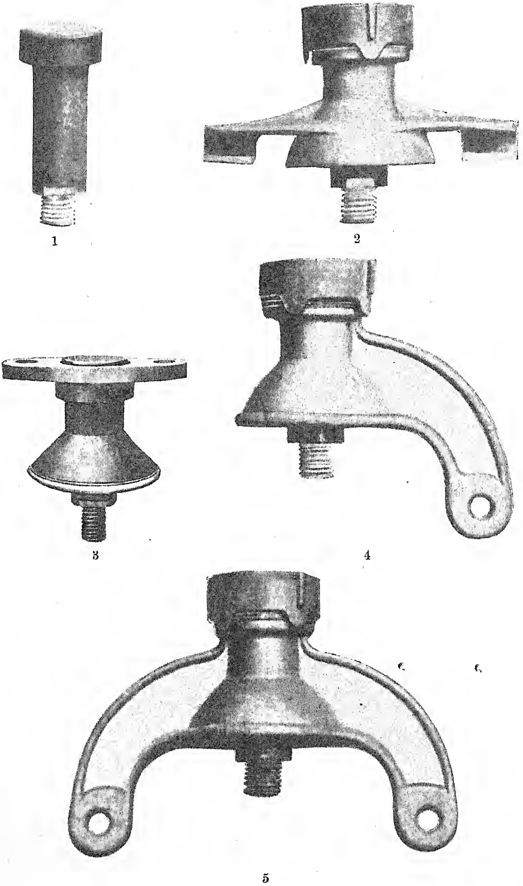


Fig. 81. Various types of insulated hangers.
1. Insulated bolt. 2. Straight line hanger. 3. Bridge hanger.
4. Single pull-off. 5. Double pull-off.

shellac and similar materials in varying proportions made up under great pressure. The body and cap are of gun-metal, bronze or malleable galvanised iron; the insulated bolt is threaded through the body from above, and the cap is then screwed on.

Sometimes the body is arranged for bolting directly up to the under surface of a bridge, in which case it is called a *bridge hanger*. The ordinary type of hanger is illustrated in figure 81, and figure 82 shews the cross-section of an insulated bolt.

Pull-offs, single and double. These are similar to the insulated hangers, but are made suitable for curves. As the trolley wire at the point of support exerts a horizontal pull due to the curvature, it is necessary that the points of attachment of the span wire should be in the same plane as the trolley wire, and yet clear of the trolley wheel. Pull-offs are wide and narrow according to whether the span wire is

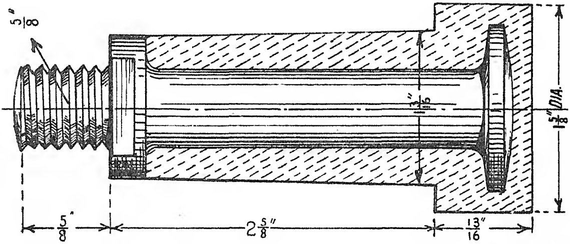


FIG. 82. Section of insulated bolt.

perpendicular to the trolley wire or at an angle. Figure 81 shews single and double pull-offs of the ordinary type. With the bow type of collector, it is not permissible to have the pull-off wire on the same level as the trolley wire, as the bow would be liable to foul. Messrs Siemens-Schuckert Werke have designed a special type of insulated hanger similar to that in general use, but with longer arms; by this means the tilting of the hanger due to the side pull of the trolley wire is reduced to safe limits.

For sharp curves on the bow system a special construction is adopted which consists of sweating to the trolley wire a short length of copper wire (beidraht). This wire is jointed to the trolley wire a short distance away from the pull-off on both sides; the trolley wire is deflected up and the extra wire down and both are clipped or sweated in a suitable ear as in figure 83. In this way the attachment of the

pull-off wire is on a level with the mean height of the trolley wire, and yet is well above the contact wire.

An iron bracket is slipped over the stud on the hanger and clamps the trolley wire in the position shewn; the ear carrying the "beidraht" is then screwed on and clamps the bracket. The length of the extra wire is 2·5 metres, and its ends are grooved and sweated to the trolley wire.

FIG. 83.

Strain insulators. These insulators are provided for insertion in the span wire for the purpose of the second insulation between the trolley wire and earth. The "Globe" strain insulator (figure 84) consists of 2 eye bolts or an eye bolt and a forked bolt locked together but insulated from each other by moulded insulation in the form of a globe. The size of the globe determines the leakage surface between the two bolts. The "Brooklyn" strain insulator (figure 84) provides an adjustment for taking up the slack in the span wire, and is made in several sizes, according to the range of the adjustment. They are made of bronze or malleable iron. Other forms of strain insulators are the double "Brooklyn," and the insulated turn-buckle for extra long adjustments.

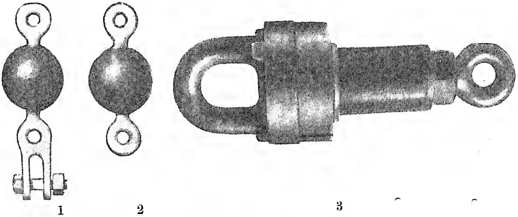


FIG. 84. Strain insulators.
1 and 2. Globe strain insulators. 3. Brooklyn strain insulator.

Wall hooks, etc. For attaching the ends of the span wire to the walls or the poles a large variety of parts is made, from the simplest hook and strap to highly ornamental wall rosettes and brackets.

Frogs are made to correspond to points in the running rails, and may be trailing or facing or spring or mechanical according to the requirements of each point. In spring frogs there is a moveable tongue held in position on one side by means of a spring, but capable of being

pushed over to the other position by the trolley wheel. In the mechanical frog the tongue is pulled over by means of an insulated wire operated by an attendant.

Figure 85 shews a top and a bottom view of a frog which may be used as a spring or a mechanical frog as required. The moveable tongue seen in one view pivots about a centre and carries with it a sheave which is shewn in the other view. This sheave is normally pulled round by means of the spring, one end of which is fixed to the frog, and keeps the tongue in the corresponding position, which may be open or closed as may be desired. If the apparatus is used as a mechanical frog, a pull-over wire or cord is required, which takes a turn round the sheave. In both cases the moveable tongue is provided with a spring.

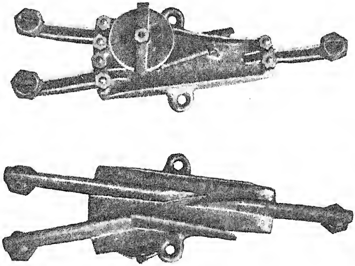


FIG. 85. Spring or mechanical frog.

Figure 86 shews a top and a bottom view of a trailing frog, which contains no moveable tongue, but provides for a junction where two tracks converge into one. With this type the trolley wheel never runs from the single track on to one of the branches but always in the reverse direction. In both types of frog provision is made for attaching and anchoring the converging trolley wires, as may be seen in the illustrations.

Various attempts have been made to introduce an automatic arrangement for switching over the points on the track and the frog. The apparatus involves the use of a solenoid or motor, operated from the overhead wire by the car driver (see page 110).

Crossings. These are used when two tracks cross, and may be either right-angled or oblique, or adjustable. When two wires cross which may require to be insulated from each other an insulated crossing is necessary. Figure 87 shews a typical crossing.

In all cases with both frogs and crossings the chief point in the design is to guard against the trolley wheel leaving the wire. With centre running fixed trolley heads the tendency to leave the wire is not so great as with side running swivelling heads. The best way to secure the proper running of the trolley wheel is to provide grooves which will guide the head by means of the wheel flanges.

As will be seen in figure 87, provision is made on the crossing for anchoring by means of pull-off wires. These wires are looped into the eyes cast on the crossing, and by applying tensions in opposite directions effectually prevent any possibility of sideways swinging. The pull-off wires are, of course, provided with strain insulators, one in each wire close to the crossing and another in each wire close to the poles.

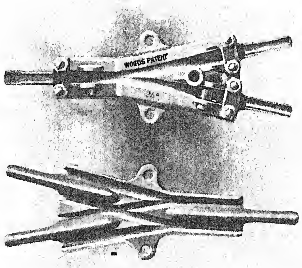


FIG. 86. Trailing frog.

Section insulators. These are required to enable the trolley wire to be divided up into sections that can be insulated from each other. The Board of Trade requires that these insulators shall be provided at distances not greater than $\frac{1}{2}$ mile (see page 445).

The old form of insulator consisted of two gun-metal castings, to which the two ends of the wire were clamped, connected by means of a tension piece in the form of one or two insulated bolts and a compression piece of wood. To provide a continuous surface for the trolley wheel a

wooden distance piece was inserted level with the trolley wire. In later forms this wooden distance piece has been eliminated, and a metal strip substituted, insulated from both end castings and supported from the

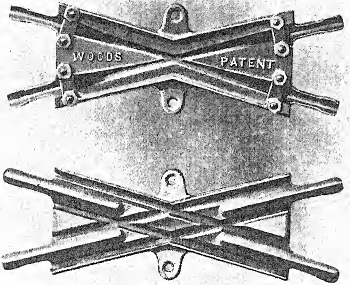


FIG. 87. Trolley wire crossing.

tension bolts. This introduces a double improvement; it eliminates the continual replacement of the wooden strip which was gradually worn out by the trolley wheels; and it provides more effective insula-

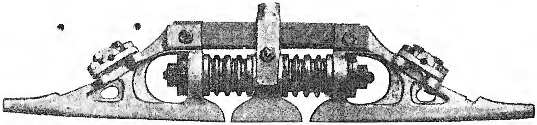


FIG. 88. Modern type of section insulator.

tion, there being two air gaps instead of a wooden surface. Figure 88 shews a section insulator of a modern type in which may be seen the provision for the terminals of the feeders.

Span wire. This is usually of stranded galvanised steel wire. The sizes in general use are as shewn in Table 10, the smaller sizes being generally used for span and guard wires, and the larger sizes for anchoring the trolley wire.

TABLE 10. *Particulars of stranded galvanised steel wires.*

Gauge	Diameter of strand inches	Diameter of single wire inches	Breaking strain* lbs.	Weight per 100 yds. lbs.
7/10	$\frac{3}{8}$	·125	4550	86
7/12	$\frac{5}{16}$	·104	3950	56
7/14	$\frac{1}{4}$	·083	2400	37
7/15	$\frac{7}{32}$	·072	1850	28·5
7/16	$\frac{3}{16}$	·066	1700	24

Poles. For tramway purposes poles are almost invariably of mild steel. In this country sectional tubular poles are generally used; but on the Continent lattice steel masts are frequently employed; wooden poles are occasionally used there and also in America.

Quite recently the British Engineering Standards Committee issued a standard specification for tubular tramway poles, a copy of which is given at the end of this chapter. From this specification it will be seen that there are three standard sizes capable of withstanding pulls of 750, 1250 and 2000 lbs. respectively. Some information is added with regard to wooden poles which may be useful in connection with tramways or railways on which such poles might be employed. The lighter poles are used for span wire and side-bracket construction on the straight, and the heavier ones for curves and terminal anchorages.

The poles are erected by being embedded in concrete generally to a depth of 6 feet. The amount of concrete varies, of course, with the nature of the ground, but an average figure is about 18 inches all round.

The distance between poles must not exceed 120 feet in accordance with the Board of Trade Regulations (see page 450).

Poles are generally ornamented by being provided with a base to cover the lower part to a height of about 4 to 5 feet above the ground, and by a finial at the top. With side-bracket construction, ornamental scroll-work is sometimes included with the staying of the bracket arm.

* Dawson's *Electric Traction Pocket-Book.*

Brackets. These are generally made of solid drawn seamless tubes varying in length from 6 feet to 16 feet, the thickness of the tube being not less than $\frac{1}{4}$ inch. They are fixed to the pole, the end being inserted into a socket in a casting which is clamped to the pole. The brackets are supported in position either by scroll-work fixed to the poles underneath the brackets, or by tie rods above the brackets, or very often by both. For short brackets tie rods are not necessary; but if the length exceeds 7 feet there should be one tie rod, and if the length exceeds 12 feet there should be two.

Flexible suspensions for use with brackets. When side-bracket construction was first used, the trolley wire was suspended rigidly from the bracket arm. It was found, however, that this method of suspension gave rise to frequent breakages of the trolley wire at the point where it was soldered to the ear, due to the constant bending at this point. In consequence, a flexible suspension was introduced, exactly similar to a span wire construction, the ends of the short span being attached to two hangers clamped to the bracket arm.

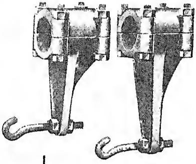


FIG. 89. Bracket arm hangers.

Figure 89 shews two bracket arm hangers of different sizes, consisting of malleable castings with a split band for clamping to the bracket. At the lower end provision is made for a hook to which one end of the span wire is attached. When guard wires are used, the hanger is extended upwards to the necessary distance above the bracket to provide a point of support for the guard wire.

The illustration in figure 90 shews a typical tramway pole with ornamental base and finial, the joints of the pole being covered with rings. The same illustration shews a bracket fitted with a flexible suspension for two trolley wires, the bracket being supported by ornamental scroll-work and strengthened with two tie rods.

Guard wires. To avoid any danger from broken telegraph or telephone wires falling on the trolley wire, it is necessary to erect guard

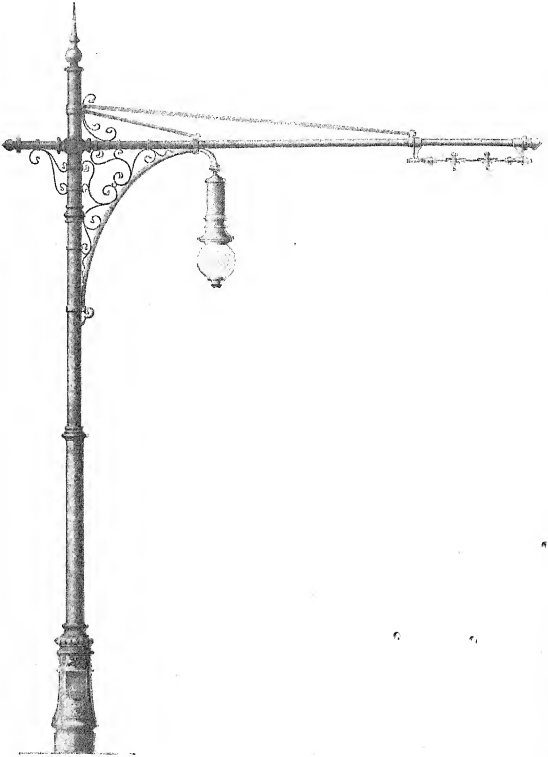


FIG. 90. Typical tramway pole with base and finial, together with side bracket and trolley wire suspension.

wires overhead whenever the trolley wire is crossed by other wires. These guard wires are simply light galvanised steel strand, similar to span wires, stretched parallel to the trolley wire, and at a minimum height of 24″ above it (see Board of Trade Regulations for guard wires, page 438).

Feeders. Feeders are connected to the trolley wires by means of cables, which are generally taken up from the feeder pillars through the centre of the poles. Near the point of attachment of the bracket arm or span wire they emerge from the pole through bushed holes and are taken to the feeder ears or the section insulators as the case may be. Figure 91 shews the clips which are used for supporting these cables, the large one being used for bracket arms and the small one for span wires. These feeder connections are always rubber-covered cables taped and braided.

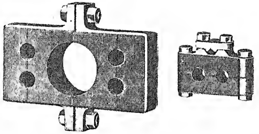


FIG. 91. Feed wire clips for bracket arm and span wires.

General remarks on overhead line material. One of the most important considerations in regard to overhead line material is durability. Many types of insulating support for trolley wires might be proposed, but all would not be equally good in this respect, and it is of course highly important to bear in mind the cost of maintenance. For this reason attention must be paid to any possibility of deterioration due to rusting. The overhead material is very often of bronze, but sometimes of malleable iron, in which case it should be painted after erection. Similarly the bracket arms must be painted, and it is important that this painting should be done before the various rings and hangers are clamped on, otherwise moisture will certainly get under the rings and attack the bare surface of the tube. For the same reason the stranded steel wires are galvanised, the poles are painted outside and tarred inside, and care should be taken that there are no pockets at the joint rings or at the top of the base in which moisture can collect.

General design of overhead construction. Having briefly described the materials used in the construction of the overhead line, it remains to consider the application of the various parts to the different types of construction.

The Board of Trade requires that the trolley wire shall be not less than 17 feet above the roadway at its lowest point except under bridges (see page 450). The height of the attachment of the span wire to the pole or the wall-rosette will therefore be at least 17 feet plus the sag of the trolley wire plus the sag of the span wire.

The sag of the span wire will depend on the weight to be supported, the tension in the wire, and the width of the road. Let T (figure 92) represent the trolley wire, and *ss* the span wire attached to the fixed points PP, the distance between which is $2l$; suppose the dip of the span wire to be d. Let W be the weight per span of the trolley wire and hanger and w the weight of the span wire; then the vertical component of the tension at P will be $\frac{1}{2}(\mathrm{W}+w)$ and by the principle of moments the horizontal component will be $\frac{1}{d}\left[\frac{1}{2}\mathrm{W}l+\frac{1}{2}w\frac{l}{2}\right]$.

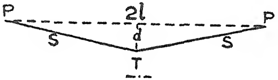


FIG. 92. Diagram illustrating the dip of the span wire.

Table 11 gives the horizontal pull on the pole corresponding to 120 feet spans of single and double track, the road width being 40 feet and the dip 1 foot. For different road widths and dips similar figures can easily be calculated.

TABLE 11. *Horizontal pull on side poles along a straight track due to tension in span wire. Road width* 40 *feet. Span wire dip* 1 *foot. Span length of trolley wire* 120 *feet. No ice or wind.*

Trolley wire size L.S.G.	Trolley wire Weight per span including hanger	Weight of span wire	Horizontal pull on poles	
			Single track	Double track
	lbs.	lbs.	lbs.	lbs.
00000	72	5	745	1108
0000	62	5	645	958
000	54	3·8	559	830
00	47	3·2	486	721
0	40	3·2	416	592

Under the worst conditions as specified on page 122, viz. $\frac{1}{8}''$ coating of ice and a wind pressure of 20 lbs. per square foot, the pulls on the poles would be increased by about 25 per cent.

If a dip of more than 1 foot in a 40 foot width is not objected to lighter poles could be used, as the pull is practically inversely proportional to the dip.

Assuming a dip of 1 foot, and a maximum sag of 15 inches in the trolley wire, the point of attachment of the span wire must be $17+1+1{\cdot}25=19{\cdot}25$ feet above the road level. This would require a pole at least 26 feet long. For wider roads and for side-bracket construction longer poles will be necessary.

Tension in pull-off wires. The tension in pull-off wires will vary with the sharpness of the curve and with the tension in the trolley wire. For a 120 foot span, if T be the tension in the trolley wire and R the radius of the curve in chains, the pull-off tension will be

$$2 \times T \times \frac{60}{66R} = \frac{1{\cdot}82T}{R}.$$

TABLE 12. *Tension in pull-off wires for curves of different radii; length of trolley wire span* 120 *feet; tension in trolley wire equal to the elastic limit. Single track.*

Trolley wire		Tension in pull-off lbs.								Extra tension due to ice and wind
L.S.G.	Tension lbs.	chs. 5	7·5	10	15	20	30	50	100	lbs.
00000	2470	900	600	450	300	225	150	90	45	82
0000	2120	770	515	386	257	193	129	77	39	78
000	1840	670	447	335	223	167	112	67	33	75
00	1600	580	416	290	194	146	97	58	29	72
0	1380	500	360	250	167	125	83	50	25	69

The figures in this table assume that there are no pull-offs between poles.

These tables will assist in the design of the overhead construction along the straight portions of the track, and for moderate curves. For sharp curves and for special places such as complicated junctions and crossings, each case must be dealt with on its merits.

Curves. The consideration of the support of trolley wires at curves must depend upon the type of trolley head in use. As already explained in a previous chapter (page 49), there are fixed and swivelling trolley heads; with the former the trolley wire must be kept close to the centre of the track, whereas with the latter a considerable deviation may be allowed without there being much risk of the wheel leaving the wire.

With the fixed trolley head the general practice is to allow a deviation on either side of the centre line of 15 to 18 inches, corresponding to a trolley pole 12 ft. 6 ins. in length. With other lengths the deviation may be taken in proportion.

With the swivelling trolley head there is no such definite rule; it is obvious that very considerable deviations may be allowed and are often employed, even on a straight track. On curves, however, it is not wise to carry this to excess, chiefly on the score of maintenance. The greater the deviation the greater the deflection of the trolley head as it passes a pull-off, and the greater the shock to the overhead construction as the trolley head passes.

As has been pointed out already in a previous chapter (page 56), these considerations do not apply to the overhead line when the bow collector is used. The smooth working of the collector is independent of the angles in the wire, and consequently the only limitation that must be adhered to is to keep the trolley wire within half a metre of the centre line of the track. With this figure it is a simple matter to calculate out the spacing of the pull-offs.

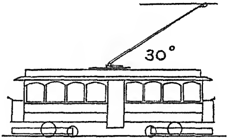


FIG. 93. Diagram of elevation of trolley pole.

As an approximate guide in setting out the construction on a curve it may be assumed that there need be only half as many pull-offs with a swivelling as with a fixed trolley head. This of course must not be regarded as a rigid rule, but is merely intended as a guide which may be modified to meet the circumstances of the case. In general therefore it will be sufficient to consider the requirements for a fixed trolley head, the conclusions arrived at being easily modified to suit a swivelling trolley head.

The deviation mentioned above may be taken as indicating the maximum permissible angle between the trolley line and the trolley pole as seen in plan. The general practice in this country is to make the normal elevation of the trolley pole 30° as in the sketch figure 93. Taking this angle, a trolley pole 12 ft. 6 ins. long when seen in plan will appear to be $12{\cdot}5 \times \cos 30° = 12{\cdot}5 \times {\cdot}866 = 10{\cdot}8$ feet; the angular deviation will be consequently (allowing an actual deviation of 16 inches

or 1·33 feet with this pole) $\sin^{-1}\frac{1\cdot33}{10\cdot8} = 7°$. In setting out the construction for a curve it will be advisable to limit the angle between the trolley pole and the wire to this value.

If the question be examined as to how the wire may be arranged so as to give the fewest points of support without this value of the angle being exceeded, it will be found that for curves of small radius the points of support lie on a circle the radius of which is a little less than

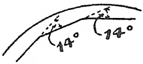


FIG. 94. Diagram illustrating the angles of the trolley wire round a curve.

the radius of the centre line of the track, and that the angle at each point is 14°, as illustrated in figure 94. In this figure the circle represents the centre line of the track, and the broken line the trolley wire, the points of support of which are situated on a smaller circle. This smaller circle is in reality the "curve of pursuit," and is the theoretical curve which the trolley wire should follow so that the angle between the trolley pole and the wire might be zero. If R be the radius of the outer curve, the radius of the inner curve will be $\sqrt{R^2 - 10\cdot8^2}$.

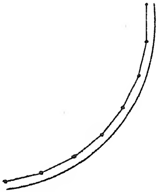


FIG. 95. Diagram illustrating the disposition of the trolley wire round a right-angle bend.

Thus for sharp curves up to about 100 feet radius there will be in a right-angle bend at least 7 angles, as 6 times 14° only amounts to 84°; and if the angle at entering and leaving the right-angle bend be half the other angles there will be 8 fixed points including the first and last as shewn in figure 95. For a fixed trolley head this is practically necessary, whereas for a swivelling trolley head it should be sufficient to reduce this number to 5 including the first and last, although there is no harm in allowing for more. This should be sufficient to enable any sharp right-angle bend to be set out.

For curves of radius greater than about 100 feet (with the above values of angle and length of trolley pole the maximum radius is 87 feet) the angles are not on this curve of pursuit, but Table 13 will shew how far apart these points may be for a fixed trolley head. This table also gives the spacing of the points for small curves, so that the construction may be set out for bends which are not right-angled.

TABLE 13. *Distances between pull-offs on curves of different radii for trolley wire in connection with fixed trolley heads. Length of trolley pole* 12 *ft.* 6 *ins. Elevation* 30°. *Deviation of trolley wire equivalent to* 16 *ins. in a span of* 120 *ft.*

Radius of centre line of track—feet	Radius of "curve of pursuit"	Distance between pull-offs
40	38′ 6″	8′ 7″
50	48′ 10″	10′ 11″
60	59′ 0″	13′ 3″
70	69′ 2″	15′ 6″
80	79′ 3″	17′ 9″
100		22′ 3″
150		33′ 6″
200		45′
300		61′
400		75′
500		87′
700		108′

Overhead construction on curves and at junctions and crossings. The foregoing deals with the requirements of the overhead line from the point of view of the tramcar; it remains to discuss the various methods of supporting and fixing the trolley wire so that it may conform to these requirements.

Many calculations might be made as to the stresses in the trolley wire and the span and pull-off wires at curves; but they would be of very little utility because of the uncertainty of the data on which they would be based. In actual practice such calculations are not made, but each case is settled on its own merits in the light of previous experience.

Figures 96—105 all deal with overhead construction and the following is a list of the symbols used with their definitions:

a Globe strain insulator.	*f* Anchor ear.
b Brooklyn strain insulator.	*i* Section insulator.
c Trolley crossing.	*l* Trolley wire.
d Double pull-off.	*p* Pole.
s Single pull-off.	*t* Straight line hanger.
e Frog.	*SW* Span wire.

At a junction either on a single or on a double track, each trolley wire from one direction branches off into two. As each of the three wires which meet in a single point is under tension some provision must be made for counteracting the unbalanced pull. This is done by strain wires from the junction to the next pole as in figure 96, which shews a double track junction.

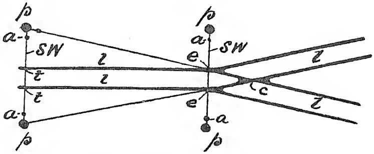


FIG. 96. Diagram illustrating the method of anchoring the trolley wire at a junction.

There are two ways in general of arranging the pull-offs round a curve. In the first, shewn diagrammatically in figure 97, a single wire

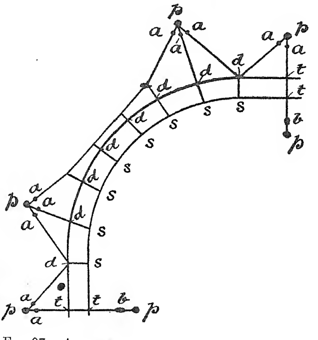


FIG. 97. Arrangement of pull-offs round a right-angle bend.

or sling is stretched across more or less parallel to the trolley wire, and from it short lengths of wire of the proper length are taken to the pull-offs. In the second method a pole or wall-hook is fixed about half-way round the curve on the outside, and pull-off wires taken from it to the trolley wire. This method is shewn diagrammatically in figure 98. The choice of methods will depend upon local conditions, such as possible

positions for poles or wall-hooks, and each case must be settled by these considerations. For curves of large radius, where there need only be one pull-off per span in addition to those at the poles, it is simplest to use the former method as shewn in figure 99.

Junctions and complicated crossings must in all cases be treated individually, and no general rules can be laid down, as the conditions

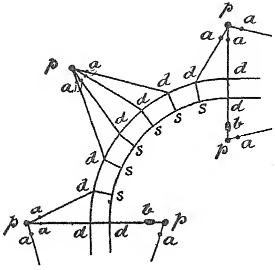


FIG. 98. Alternative arrangement of pull-offs round a right-angle bend.

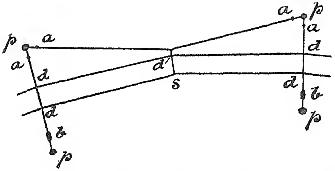


FIG. 99. Arrangement of pull-off at the middle point of a span.

vary for each case. Two examples however are shewn in figures 100 and 101 in which are indicated constructions for two particular cases, the constructions having been laid out in each case to suit the local conditions.

In figure 100 the construction is laid out for use with a bow collector, and may be contrasted with figure 101, in which the construction is suitable for a centre running fixed trolley head. For a swivelling trolley head the number of angles may be rather less than are required for the latter*.

* The authors wish to acknowledge the assistance they have obtained in connection with overhead construction from Dawson's *Electric Traction* which is still one of the best books on this subject.

Anchoring. It is advisable to anchor each section or half-mile length either in the middle or at both ends, or both. If the anchorage is at the ends, the pull on the section insulator is relieved. Figure 102 shews a double anchorage and figure 103 the method of anchoring at

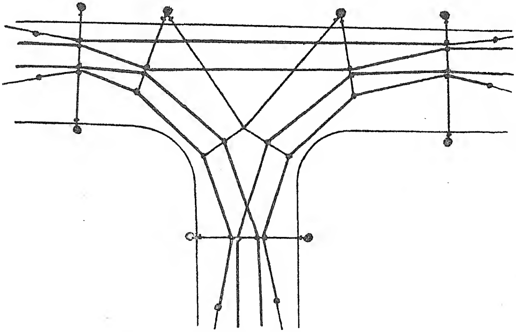


FIG. 100. Overhead construction (bow collector).

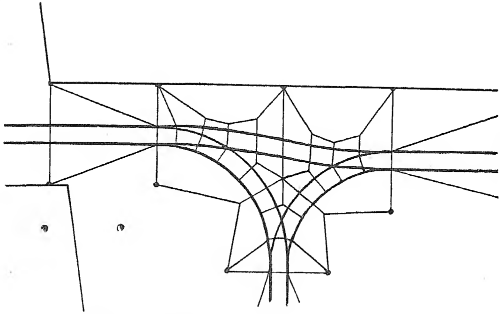


FIG. 101. Overhead construction (central running trolley).

the ends of the section. At the end of the line the trolley wire is generally anchored in the manner shewn in figure 104, the end of the wire being held in a "terminal clamp" which is attached to two strain wires from terminal poles.

At the approach to a bridge where the level of the trolley wire is a good deal below the ordinary level in the open, it may be advisable to reinforce the span wire support so as to take the extra downward pull due to the deflection of the trolley wire. This may be done by adding an extra span wire above the ordinary one, as shewn in figure 105.

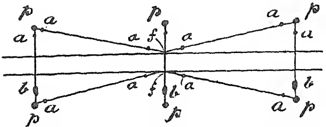


FIG. 102. Double anchorage for trolley wire in the centre of a half-mile section.

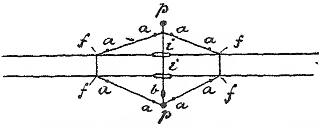


FIG. 103. Anchorage for trolley wire at the ends of a half-mile section.

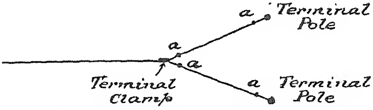


FIG. 104. Terminal anchorage for trolley wire.

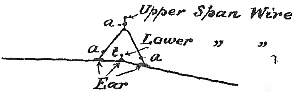


FIG. 105. Additional support for trolley wire at the approach to a low bridge.

Overhead construction at a swing-bridge. It is necessary in the case of swing-bridges to provide against the possibility of a car running too far when approaching an open bridge. Specially designed contact pieces provide a continuous running surface for the trolley wheel at the point where the overhead wire on the bridge joins that on the approach, and the circuit is broken when the bridge swings clear.

It is further necessary to render a portion of the overhead wire inactive before the bridge is reached. In figure 106 the portion AB is fed through the trolley wire on the bridge from E; and the portion CD is fed only from F, since insulators are placed at A and C. Consequently the car cannot obtain current beyond A in the one case and C in the other, unless the trolley head was inadvertently put on to the wrong trolley wire. The insulators at A and C are situated at such a distance from the bridge that a car cannot by its momentum at ordinary speeds run over the intervening space.

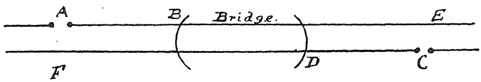


FIG. 106. Arrangement of overhead construction for a swing bridge.

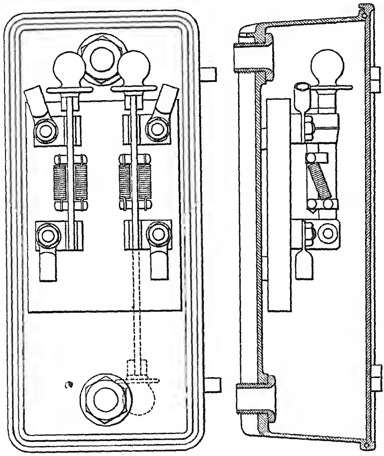


FIG. 107. Section switch box. (Estler Bros.)

Feeder and Switch Boxes. The overhead line must be constructed in sections not exceeding one-half of a mile in length (see page 450). For this purpose a switch box is provided which, if feeders have not to be accommodated, is usually fixed to the pole itself. Figure 107 shews a typical box in which two switches are located, one for each trolley wire, the two terminals of each switch being connected

to the ends of one section insulator. The boxes are constructed to accommodate telephone and test terminals in connection with the Board of Trade panel when desired, in addition to the switches above

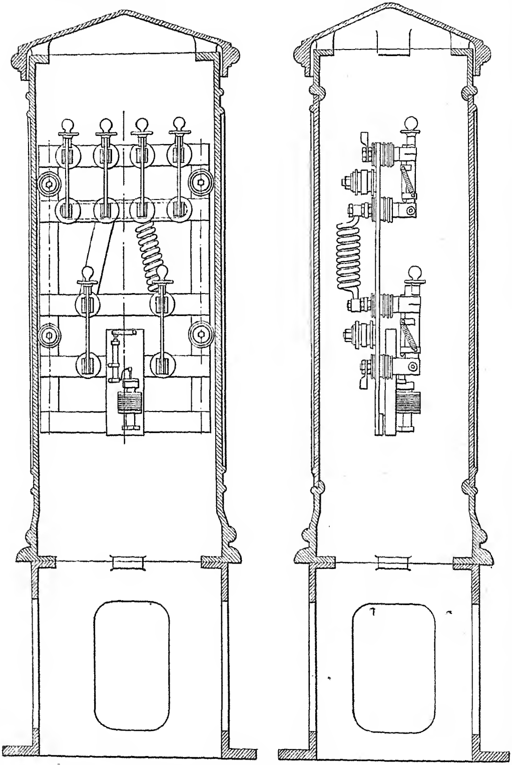


FIG. 108. Feeder pillar. (Estler Bros.)

mentioned. When feeders have to be accommodated a more substantial structure is employed in the form of a feeder pillar standing on the

ground near the tramway pole. Figure 108 is a good example of a modern feeder pillar which provides, as is now usual, a double insulation between the switches and the pillar itself. The switches are mounted on an iron frame from which they are insulated, and the frame is again insulated from the pillar. The pillar shewn in figure 108 not only provides for the positive and negative feeders, but enables the line to be sectionalised if desired. In addition it accommodates a choking coil and lightning arrester, which are shewn, and telephone and test terminals if desired.

Tower wagon. For the erection and maintenance of the overhead line a special tower wagon is necessary. This consists of a simple construction built up on a suitable base, providing a platform on which the man can stand so that the trolley wire is at a convenient level for him. The wagon is generally pulled by a single horse, and is in charge of a driver who receives instructions from the wireman.

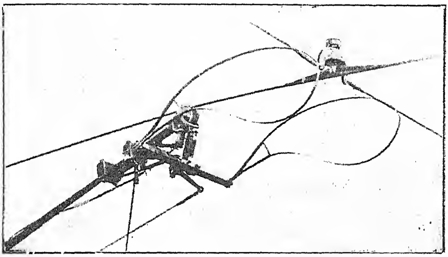


FIG. 109. Overhead equipment tester. (Everett, Edgcumbe & Co.)

Testing of insulators. Each separate insulator must be tested once a month (see page 450). The test consists of (1) connecting the span wire to earth through a suitable detector; if the insulation between the trolley wire and span wire is defective a deflection will be obtained; (2) connecting the span wire to the overhead trolley wire through a suitable detector. Should the insulator between the span wire and the bracket arm or other support be defective, a deflection will be obtained. A device carried by the trolley arm which automatically makes the above connections as the car runs along is used, on special testing occasions, on the Metropolitan Electric Tramways. This apparatus is illustrated in figure 109. A change-over switch is provided, so that it is easy to test one or other of the two insulations at a given support. They obviously cannot be tested simultaneously.

Automatic electric tramway signalling. On single lines it is sometimes desirable to use signals. For instance, when a double track converges into single track which again diverges into double track, signals are valuable when the points of convergence and divergence are invisible from each other. One car must not enter the single track section from either direction when it is already occupied. In this case the single track section would be supplied with two overhead wires. In Harvey's signal a semaphore arm is operated by a solenoid which receives current from the trolley wire when a car is about to pass on to the single section. The contact is made by the trolley wheel when it passes under a metal piece and presses it into contact with the overhead wire. When the arm has been raised by the solenoid it is held in position by a catch which can be released by an electromagnet on its being excited. The excitation however cannot occur until the car has run over the single section on to the double track and then operated a second overhead contact. In the Brecknell, Munro and Rogers system lights are used instead of the semaphore arm, and these are rendered visible in daylight by a suitable screening arrangement.

BRITISH STANDARD SPECIFICATION FOR TUBULAR TRAMWAY POLES.

Classes. The poles shall be of mild steel free of all defects and shall be of three classes:

Light pole,
Medium pole,
Heavy pole.

Construction. The sectional poles shall be either solid drawn or lap-welded wrought steel, free of all defects, made up in three sections, swaged together when hot so as to make a perfect joint. The lap-welded seams in the sections shall be set at an angle of one hundred and twenty degrees (120°) to each other.

The taper poles shall be of wrought steel, free of all defects, rolled in one length and butt-welded the entire length. The butt-welding shall be carried out at an even temperature without over-heating and no pole shall show any signs of burning at the weld.

Overall length. The overall length of poles of all classes shall be thirty-one feet (31 ft.).

Length of joints. The length of the telescope joint in the sectional poles shall be eighteen inches (18 ins.).

Length of sections. The length of the sections shall be:

Top section	8 feet 6 inches,
Middle section	8 feet 6 inches,
Bottom section	17 feet.

Outside diameters. The outside diameters, in inches, of the three classes of both sectional and taper poles shall be:

SECTIONAL POLES.

Class	Top	Middle	Bottom
Light	$5\frac{1}{2}$ ins.	$6\frac{1}{2}$ ins.	$7\frac{1}{2}$ ins.
Medium	$6\frac{1}{2}$ ins.	$7\frac{1}{2}$ ins.	$8\frac{1}{2}$ ins.
Heavy	$7\frac{1}{2}$ ins.	$8\frac{1}{2}$ ins.	$9\frac{1}{2}$ ins.

TAPER POLES.

Class	Top	Outside diameter 9 ft. 6 ins. from base
Light	$4\frac{3}{4}$ ins.	$7\frac{1}{2}$ ins.
Medium	$5\frac{3}{4}$ ins.	$8\frac{1}{2}$ ins.
Heavy	$6\frac{3}{4}$ ins.	$9\frac{1}{2}$ ins.

Minimum thickness. The thickness of metal in any pole shall not be less than one-quarter of an inch ($\frac{1}{4}$ in.).

Straightness. The completed poles shall be straight and true over their entire length to within one-quarter of an inch ($\frac{1}{4}$ in.).

Variation in diameter. The section of any pole shall be as nearly circular as possible, not varying in diameter by more than one-sixteenth of an inch ($\frac{1}{16}$ in.) from the adopted standard.

Drop test. Five per cent. (5 °/$_\circ$) of each class of sectional pole shall be subjected to the following drop test:

The pole shall be dropped vertically, butt downwards, three times in succession, from a height of 6 feet on to a hard wood block six inches thick laid on a concrete foundation, without shewing any signs of telescoping or loosening of joints.

Bending tests. Five per cent. (5 °/$_\circ$) of each class of both sectional and taper pole shall be subjected to the following bending tests:

The pole shall, in each case, be rigidly supported for 6 feet from the butt, and loaded, as a cantilever, eighteen inches (18 ins.) from the top, the load being applied at right angles to the axle of the pole which shall be fixed horizontally. Upon the application of the following loads

in lbs., the temporary deflection and permanent set, measured at the point of application of the load, shall not exceed the figures stated in the tables.

Class of pole	Load in lbs. for temporary deflection not exceeding 6 ins.	Load in lbs. for permanent set not exceeding ½ in.
Light	750 lbs.	1000 lbs.
Medium	1250 „	1750 „
Heavy	2000 „	2500 „

Rejection. In the event of any pole of the above-mentioned five per cent. (5 °/₀) not fulfilling the test requirements a further five per cent. (5 °/₀) shall be subjected to the tests enumerated above. Should any further failure occur the whole parcel from which the poles have been selected shall be liable to rejection.

Provision of testing apparatus. The maker, at his own expense, and to the satisfaction of the engineer shall provide all the necessary testing apparatus, at his own works, for carrying out the above-mentioned tests.

Wooden poles. The following information with regard to wooden poles may be useful.

TABLE 14*. *American yellow pine or cedar. Railway poles.*

Length feet	Diameter top	Diameter butt	Section	Weight lbs.	Stress at top to deflect 7″ lbs.
27	6″	8″	circular	360—450	350
27	7″	9″	circular	450—560	500
27	7″	9″	octagonal	500—620	500
28	7″	9″	circular	490—600	500
28	7″	9″	octagonal	520—650	500
28	8″	10″	circular	620—750	750
28	8″	10″	octagonal	650—800	750
30	7″	9″	circular	530—670	450
30	7″	9″	octagonal	560—700	450
30	8″	10″	circular	660—820	700
30	8″	10″	octagonal	700—850	700
30	8″	12″	octagonal	900—1150	850

* Abbott, *Electrical Transmission of Energy*, p. 132.

TABLE 15*. *Tensile and crushing strengths of various woods.*

Material	Tensile strength lbs. per sq. in.	Crushing strength lbs. per sq. in.
Ash, white	10000—17000	5000—8000
Cedar	10000—12000	4500—5900
Oak, English	10000	6500—9500
Pine, pitch	7600	6800
Pine, yellow	5000—12000	5300—6500
Spruce, white	5000—10000	4500—6000

Sir William Preece† gives the following figures for round and square poles, creosoted for telegraph lines (Norwegian or Swedish red fir):

$$\text{Breaking load in lbs.} = 765 \frac{D^3}{l} \text{ for round poles,}$$

$$= 800 \frac{bd^2}{l} \text{ for square poles,}$$

where D is the diameter of the pole, and l the length above ground, in inches, b the breadth and d the depth in inches.

The most economical taper for a wooden pole is such that the diameter at the ground level is $\frac{3}{2}$ times the diameter at the top.

* Abbott, *Electrical Transmission of Energy*, p. 53.
† *Electrician*, Sept. 18, 1885, p. 347.

CHAPTER 8.

PART 1.

SLOTTED CONDUIT TRAMWAY SYSTEMS.

It is not intended to trace the early history of the attempts which have been made to supply energy to cars by means other than the overhead system; but recent work in this direction may be considered briefly under two groups:

(1) the slotted conduit system,

(2) the surface contact system.

The slotted conduit system consists of an underground conduit running the whole length of the line, with a narrow opening at the surface to permit of a "plough" or current collector passing down from the car into the conduit. The conductor or conductors from which electrical energy has to be taken are supported on insulators fixed to the structure of the conduit, and rubbing contact is made between them and the collector. In this manner the car can receive energy with the same facility that energy is received from an overhead conductor. It can be easily understood that such a system as this is expensive to construct, especially in towns or cities where there are already gas and water pipes, and possibly electric light mains under the roadway; in fact it is only in thickly populated districts that the large capital outlay can be at all justified. Further than this the system has to be properly drained, provision must be made for cleaning out the conduit, and the structure must be sufficiently strong to prevent the closing in of the slot. Once the conduit is constructed the positive and negative mains can be supported on either side, and in this way electrolytic action on underground metal can be avoided since the rails need not be used as a return circuit. There have been examples in which only the positive main was insulated and the rails used as a return, but nowadays both positive and negative mains are insulated, and the plough has been so successfully developed that it gives entire satisfaction when collecting from both conductors.

There are two types of slotted conduit systems, that is, the slot is either at the side or at the centre of the track. The London County Council's system is an example of centre slot construction, but experiments are being made in North London with the side slot, so that possibly in time the London system may be a combination of the two types. It would at first sight appear that since the slot has to be formed between two longitudinal rails, these should also serve for the wheels on one side of the track. In places where it is considered that the amount of iron exposed to the road should be as small as possible the side slot has an advantage. It, however, requires a wider slot on account of the accommodation which it must give for the flange of the wheel. A standard tyre requires a slot 1″ wide, whereas for the plough or collector ¾″ is sufficient. Not only is the narrow slot safer, but it diminishes the amount of dirt which collects in the conduit, and thereby reduces an important item in the cost of running. In side slot construction the wheel itself throws more dirt into the conduit than would otherwise be the case, whereas in centre slot construction the slot rails are not only nearer together, but can be slightly higher than the running rails. The width and position of the slot is therefore one of the predominating factors in the choice of the system. For these reasons the extra cost of centre slot construction may at times seem to be justified.

The **yoke** is a massive casting which supports the slot rails and is designed to give exceptional strength in order to withstand the forces which tend to close in the slot. There are two types of yoke employed in conduit construction. The "extended" type is being extensively used and is that originally employed at New York. Not only does it support the slot rails, but an extension on either side to which the running rails are fixed serves the purpose of the sleeper in ordinary railway practice. The "short" yoke has no such extensions and was exclusively used on the London County Council's system. The type of road laid down during the early stages of this system is shewn in section in figure 110, from which it will be seen that both the slot and running rails are tied to lugs cast on either side of the yoke. The present practice of the London County Council is to employ extended and short yokes alternately at intervals of 3 ft. 9 ins. Details of these yokes are shewn in figure 111. The "short" yokes it will be noticed are not tied to the running rails as formerly. The "extended" yokes are embedded in the concrete and hold the running rails firmly on their seating. Between the bottom of the running rail and the yoke extension is placed a thin wooden packing piece, and the rail is secured in position by plates on either side which bridge over the flange and are bolted to the extension. In order to give an adjustment for gauge,

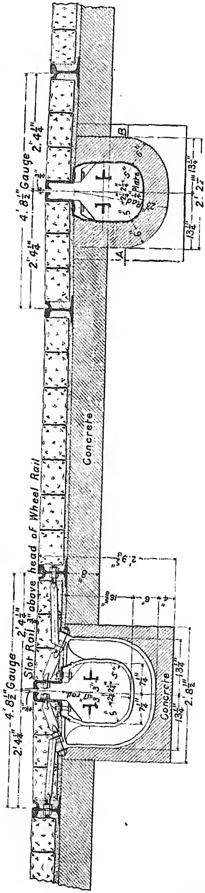


FIG. 110. Old type of L. C. C. conduit construction.

taper keys on each side of the rail are driven in between the plates and lugs cast on the yoke extension. The slot and running rails are in addition bolted together by tie bars. The extensive use of concrete in London has not necessitated the use of an extended yoke of such

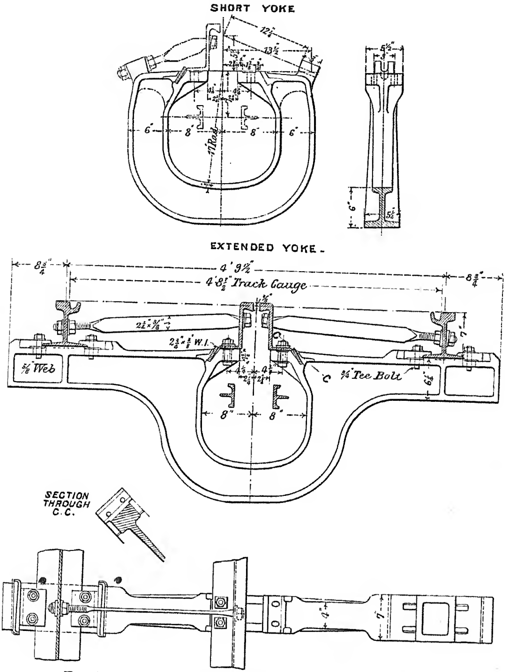


FIG. 111. Details of yokes in modern L. C. C. construction.

massive proportions as at New York, where the yoke is relied upon to act as a sleeper and is provided with an additional lower flange which bridges across the roadway. At the joint of the running rails inverted pieces of rail are used as additional anchors.

A section of the Bournemouth Road is given in figure 112, and is a good example of side slot construction, the conduits being under the two inner rails in double track. The yoke is of the "short" type, and the slot rail on the inner side is connected by tie bars with the wheel rail at every other yoke. The joints in the slot rails are placed between the yokes and are of the "continuous" type.

The **pavement** between and on either side of the rails may be of either wood blocks or granite setts. Wood blocks are cheaper, but do not wear so long as granite. Moreover they swell when wet and bring about undue stresses which tend to close up the slot. Guernsey or Aberdeen granite has been extensively employed and is laid on a layer of shingle which is evenly spread over the concrete surface. A three to one sand and cement mixture is then poured over the setts and grouted in. This is probably the most permanent form of paving at present in use.

The **conductor rails** are of high conductivity steel usually weighing 22 lbs. per yard bonded at the joints, and supported on insulators spaced out at intervals of 15 feet. Each insulator is submitted to a high pressure test, and care is taken that the leakage surfaces are protected from stray cement when the bolts are being inserted. Figure 113 gives a section of one of the London insulators. The cables between the section pillars and the rails are carried in stoneware ducts buried in the concrete.

At junctions and crossings a break in the conductor rails varying in length from 7 to 12 feet is necessary, and the car must coast over these spaces. On overhead systems the only place where a car cannot obtain current is at a section insulator, and the distance is very small. On conduit roads the lights may at times be extinguished for a few seconds.

Points are generally operated at boxes at the side of the track and involve a good deal of special work. In centre slot construction the running rail and slot rail points are separate, but in side slot construction this is not so. Figure 114 gives details of running rail and slot rail points and the mechanism in the London centre slot construction. Each of the running rails is provided with a moveable point of the usual construction. The slot rail points are however different. The latest type is shown in the figure and consists of two tongues which move under a protecting casting, flush with the roadway, and together serve as a guide for the plough, directing it into one slot or the other according to the position of the tongues. In this way no moving metal is exposed to the surface of the road. The operation is effected by levers from the side of the track.

Connett's combined slot and rail point*. At the junction of two tracks where the side slot is adhered to, the tongue serves to deflect both the flange of the wheel and the collector. Ledges must be provided on either side of the tongue of sufficient width to support it properly in its two positions. These ledges when fixed necessitate the widening of the slot, in some cases to as much as $1\frac{3}{4}''$; and in places where it is considered dangerous to have such width the slot has been deflected

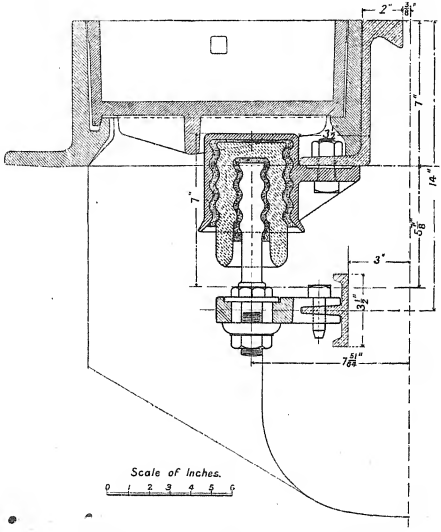


FIG. 113. Conductor rail insulator in L. C. C. conduit system.

to the centre of the track, where it need be only $\frac{3}{4}''$ wide, until the crossing has been passed. This latter method is expensive, and a considerable saving could be effected if a satisfactory combined slot and rail point could be constructed which would allow of the one inch slot being preserved throughout. To meet this difficulty Mr A. N. Connett has devised, and carried into successful

* The authors are indebted to Mr Connett for the information and drawings in the text.

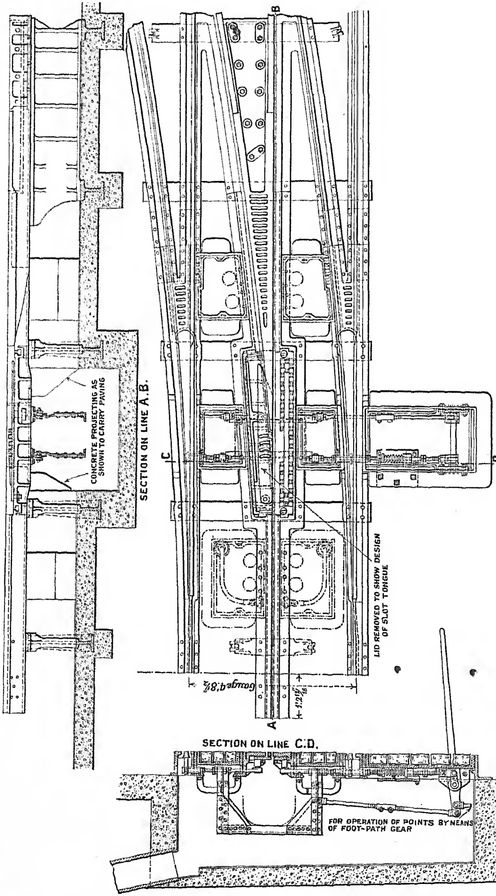


FIG. 114. Construction of slot and rail points in L.C.C. conduit system.

operation, such a combined slot and rail point, of which the following is a description. Referring to figure 115 a transverve slot is provided at the side of the road for the insertion of a bar or lever A which when moved through an angle of 80° performs two operations. First, it moves the ledge on which the tongue ultimately rests, and secondly it moves the tongue itself. In fact, the essence of the arrangement is the employment of moveable ledges. In the figure the tongue B is in such a position as to provide the straight slot and rests upon a ledge C. The ledge D is then sufficiently near to the side to secure a free passage for the collector along the straight. Suppose now it is required to deflect the car from the straight, the lever A is put over into its other extreme position. The upper sector moves a single U-shaped casting to which the ledges C and D are pivoted, and consequently they are each deflected to the left.

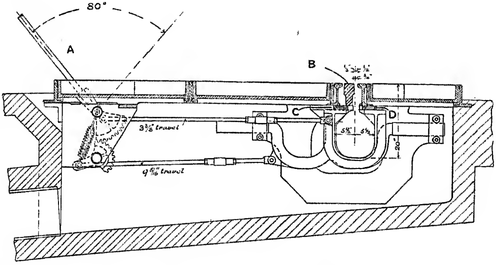


FIG. 115. Sectional elevation of Connett's combined slot and rail point.

Ledge C is thus moved away so as not to obstruct the left hand slot and ledge D is moved into position under the tongue B, the operation being such that the ledge D is under the tongue before ledge C leaves it, thereby providing a continuous support.

During the assumed motion of the lever A to the right the lower sector has been turning and has moved a double U-shaped casting to the right. The centre projection of this casting is provided with a slot which engages a pin fixed to the tongue, but it is only near the end of the throw that the pin is actually engaged. The tongue is then moved over to the right thereby opening up the left hand slot, and the tongue then rests upon the ledge D. Figure 116 gives details of the arrangement in plan. The ledges CD extend to a point along the line just beyond the end of the tongue, and are there pivoted to a fixed casting. They rest in grooves in the castings E and F respectively

which are bolted to the main structure and serve as a guide during movement.

The tongue itself is made of Hadfield's Era manganese steel and has a length of about 11 ft. One side of it is curved to suit the radius at which the deflection is required, the other being straight. The use of moveable ledges enables side slot construction to be maintained throughout, without increasing the normal width of the slot, and renders unnecessary central slot construction at crossings.

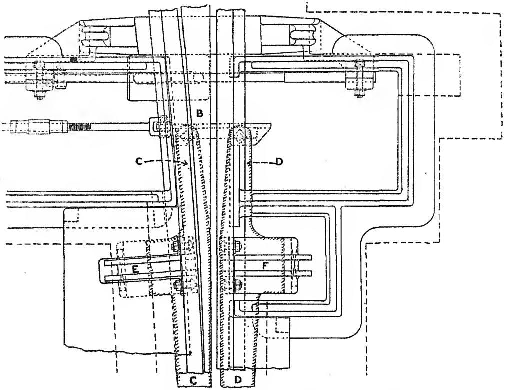


FIG. 116. Plan of Connett's combined slot and rail point.

Siemens-Schuckert combined slot and rail point. As is well known, there are in Berlin several streets and open spaces in which overhead construction for the electric tramway is prohibited. In the past these parts were worked by storage batteries carried on the cars, the batteries being charged from the trolley line while the cars were running over the other parts of the system.

This method was abandoned in favour of a combined trolley and conduit system, and short lengths of conduit construction were laid down in the special parts. The type of conduit employed was the side slot, and as in England this involved a special construction at points. Messrs Siemens-Schuckert, who installed the conduits, designed a combined slot and rail point for this purpose, and this has been successfully used since 1902.

The principle of this special point can be understood by reference to figures 117 and 118. The former shews the construction in elevation and the latter in plan. The function of the apparatus is the same as that of the combined slot and rail point described above, namely to support the moveable point of the rail tongue in both its positions without the framework of the support obstructing the passage of the plough in the slot.

As will be seen from the two figures, the essential part of the apparatus consists of a half-yoke g which can swing from one side of the conduit to the other. This yoke is pivoted by means of the

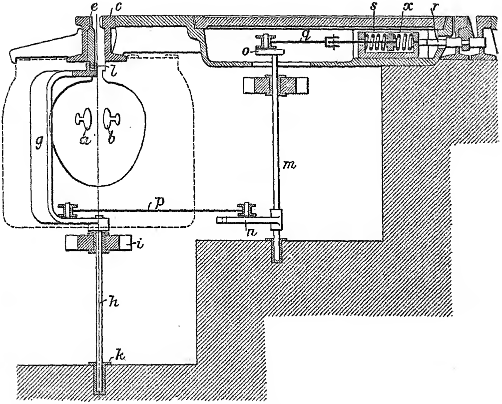


FIG. 117. Sectional elevation of Siemens-Schuckert combined slot and rail point.

vertical rod h which can turn in the bearing i and the footstep k. The point of the tongue e rests on the top of the yoke, and moves with it by reason of a pin joint l between the tongue and the yoke. The centre about which the yoke rotates passes through the centre of the slot, and the pin l is displaced from the centre by an amount which secures that the tongue shall move across the slot while the yoke rotates through the angle shewn in the figure. Thus when the tongue and the yoke are to the left, the slot and the conduit are open for the passage of the plough from the right hand track, and vice versâ.

The yoke is pulled or pushed over by the rod p and the lever arm n. The spring v working under compression ensures a complete movement of the yoke, and provides against any tendency of the tongue to stick in mid-position. The lever arm n is turned by the spindle m and the connecting rod q, and suitable means are provided by the agency of electromagnets so that the car driver can operate the point with a long rod from the car platform. A flexible connection is inserted between the rod q and the point rod r by means of the spring x, the centre of which is attached to the rod q and the ends to

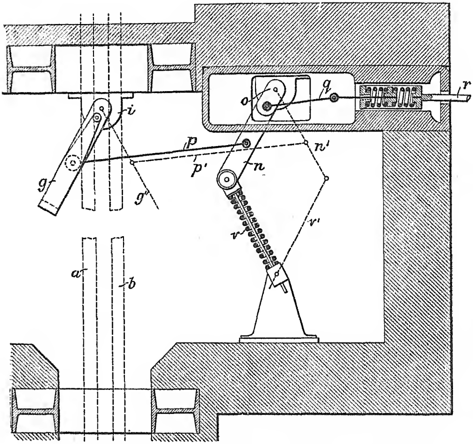


FIG. 118. Plan of Siemens-Schuckert combined slot and rail point.

a cast iron box s fixed to the rod r. This flexible connection permits of some difference in the travel of the two rods. In order to facilitate the working of this combined point, the tongue moving in the slot is balanced about its pivot by a counterweight.

The plough, plough-carrier, and plough-pit. The usual construction of plough is shewn in figure 119. It illustrates the plough in use at Bournemouth, but that of the London County Council and that used in New York* are very similar. The head is of cast steel,

* See *Tramway and Railway World*, Feb. 8, 1906, p. 138.

and the lower portion is of wood to which are fastened the supports for the rubbing shoes. The shoes themselves are of cast iron and are pressed outwards by springs. The connection between the shoes on each side and the respective vertical insulated conductors is made by a bare copper wire which acts as a fuse and melts at about 200 amperes. The illustration shews the change-over switch which is used on combined overhead and conduit systems. It is usually located under one of the car seats. The trolley-wheel and rail, in one position of the switch, are connected respectively to the same conductors on the car as the positive and negative underground rail conductors when the

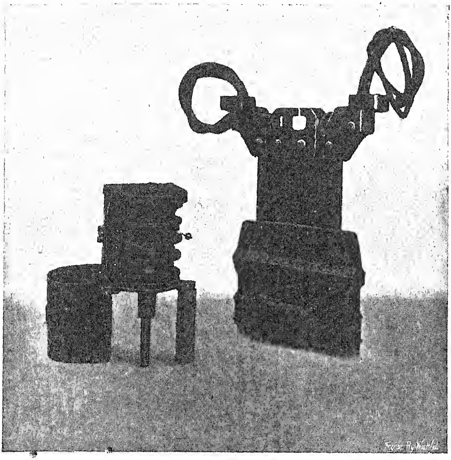


FIG. 119. Plough and change-over switch for combined conduit and trolley systems.

switch is in its other position. The raising and lowering of the plough are usually carried out by aid of a hand operated screw and double chain gear. The plough carrier, with plough in its lowest position, is shewn in figure 120, and is attached to a Brill maximum traction truck. It is of course necessary to raise or lower the plough when the car is over a properly constructed pit. The pit is provided with two moveable covers, which are operated by the movement of a bar or

lever passing through a slot at the side of the track. The covers can be separated to a width of $9\frac{5}{8}''$. When closed the covers are separated to the extent of $\frac{3}{4}''$, the space between them forming a portion of the slot, and being in line with the slot rails. By an arrangement of bell-crank levers and a horizontal shaft operated as above stated the covers preserve a parallel motion when passing from one position to the other.

Section insulation is carried out at half-mile intervals on systems in the United Kingdom. A section insulation space and sump pit are shewn in figure 121, from which it will be seen that the conductor rails are entirely discontinued, and so eased off that the plough can totally break contact with one set before making contact with the next. The

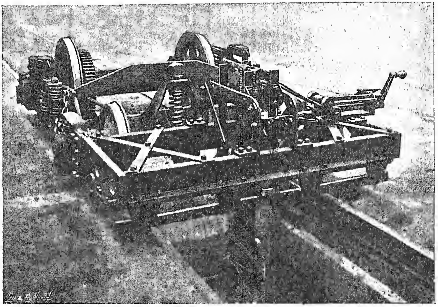


FIG. 120. Plough carrier in L.C.C. conduit system.

polarity of the sections can be changed if desired, since each is connected by a conductor to a change-over switch in the power house or sub-station. When a leak occurs on one of the two conductors comprising a half-mile section, this is at once shewn by a suitable detector, and that conductor can be put to the negative pole of the system. This is an important point, since the effect of electric osmosis is to drive moisture from the positive to the negative pole and thereby produce a higher insulation resistance at the positive pole.

Cleaning. It is most important to keep the conduit clean, and this is quite a considerable item so far as cost is concerned. The anticipated cost of cleaning in London was £100 per annum per mile of single track*. The draining and cleaning pit as used on the

* See *Tramway and Railway World*, June 11, 1903.

London system is shewn in figure 122. Mr Rider points out that London is specially troubled in respect to the amount of mud which collects in the conduits, due probably to the very heavy traffic. On about 50 miles of single track 3000 tons have been removed in a year, and nightly employment is given to a large staff of cleaners.

At New York a specially constructed scraper is employed. It is provided with india-rubber where it comes in contact with the sides of the conduit, and is drawn along the track. It has been experimented with in London, but was found to get quickly choked up. Hand scrapers are now used and give greater satisfaction.

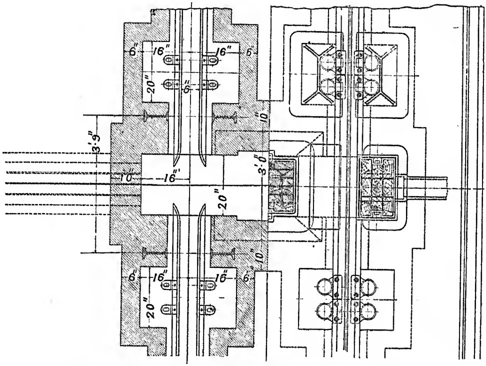


FIG. 121. Section insulation and sump pit in Bournemouth conduit system.

The **Board of Trade Regulations** were originally drafted to meet the requirements of conduit systems in which only one insulated conductor is employed. The rails were assumed to form the return conductor, and under these circumstances the Board of Trade Regulations must be conformed with. When, however, the return is insulated no Board of Trade Panel need be employed. It is obviously desirable to be able to detect when one of the conductors develops a fault, as for instance, when the plough collector gets to earth at one of its two conductors. This puts the conductor rail with which it is in contact to earth. Provision is made on the London County Council tramways for shewing this by lighting an incandescent lamp. The car can thus

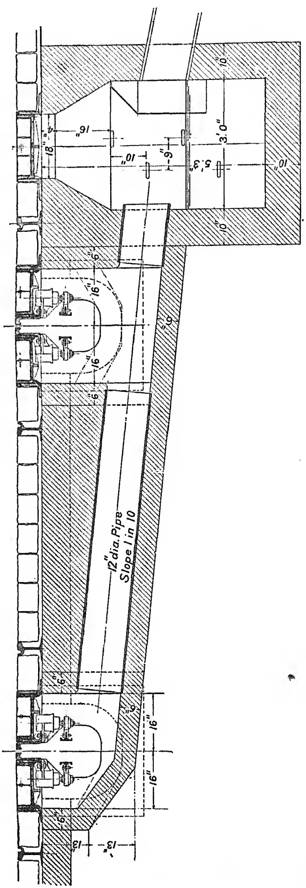


FIG. 122. Section of draining and cleaning pit in L. C. C. conduit system.

be followed from section to section by watching the detector lamps in the sub-stations; as the fault reaches each half-mile section, the faulty conductor of that section is connected to the negative terminal of supply. The Board of Trade Regulations relating to conduits are given in the Appendix, p. 446.

PART 2.

SURFACE CONTACT TRAMWAY SYSTEMS.

The surface contact system comes next to the slotted conduit system so far as mileage is concerned. In this system a series of surface contacts or studs about 10 feet apart are arranged in the line of the track, and are intended to become automatically connected to an underground conductor only when the car is over them. Fixed underneath the car are sliding conductors, or "skates," which make contact with the studs, and energy is thereby transmitted to the car by means of the electric current. The rails are used as the return just as in the overhead system. The first cost of this system, although greater than that of the overhead system, is considerably less than that of the slotted conduit. In the previous edition of this book the early attempts to make a successful system were described, and for the purposes of classification three groups were chosen.

(1) The system in which insulated sections are rendered alive by the aid of a mechanical contact carried by the car.

(2) The system in which an electromagnet, carried by the car, actuates an underground contact.

(3) The system in which an electromagnetic mechanism underground makes contact by the passage of an electric current from the car.

Group (1). A modification of the *Kingsland* system* is included in this group and is being installed at Benares in India over a distance of about ten miles. Figure 123 gives a cross-section of the normal construction of the track, and a cross-section of the track through a contact stud. The studs are spaced out at intervals of about 15 feet, and are automatically connected to and disconnected from the supply feeder by a switch which is operated by a bar fixed to the axle boxes of the car. As shewn in figure 123 the axle of the switch is vertical and carries a lever which projects across the bottom of the double rail

* The authors are indebted to Mr R. Brown of the Traction Corporation Ltd. for the information supplied in connection with his system.

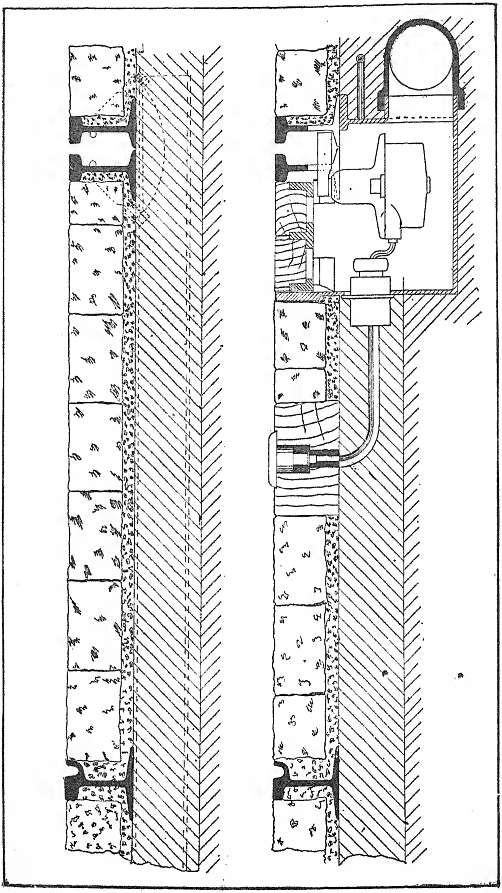


FIG. 123. Cross-section of the track in the Kingsland modified system.

conduit at the side of the track. The lever is turned through 90° against the force of torsion in a strong volute spring inside the switch box, and on being released flies back to its normal position thereby breaking the circuit between the feeder and stud. The operating bar which is fixed to the axle boxes of the car has a length somewhat greater than the distance between adjacent surface contacts, and hangs down into the rail conduit. The result is that once a switch-lever is turned from its normal position it is held there until the next switch-lever in the direction of motion has been operated, and so on. In this

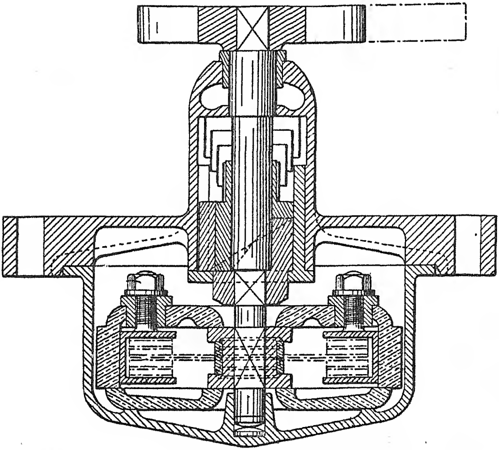


FIG. 124. Elevation of switch and switch-box in the Kingsland modified system.

manner one switch is always made before the other is broken. The switch and switch-box are shewn in sectional elevation and plan in figures 124 and 125, in the latter of which the operating bar is shewn just on the point of moving the switch lever from its normal position. The position of the lever and operating bar when the switch is operated is indicated by dotted lines. The skate collector is carried by the under-truck from which it is insulated, and rubs over the surface studs as the car runs along. The switches are contained in boxes which are let into a drain at the side of the track, thereby providing for drainage of

the conduit. It is claimed for this system that its first cost is not nearly so large as the slotted conduit system, and its installation is not much more costly than the overhead system. The weight of the extra equipment is not great, and no magnetising current is required for the skate as is the case in those systems which are dealt with in the next group.

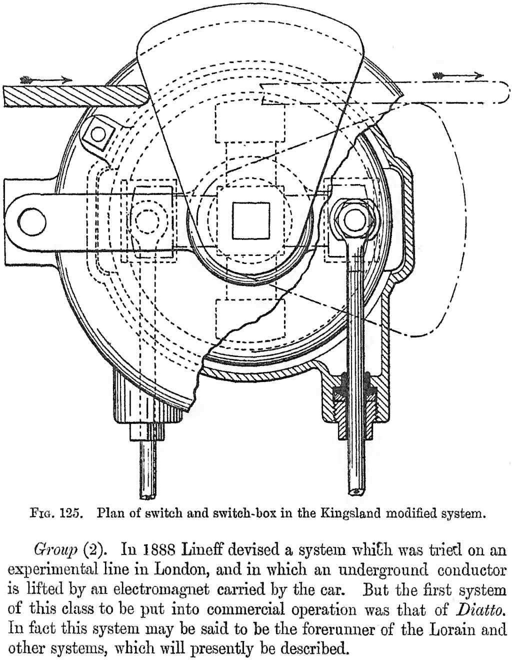


FIG. 125. Plan of switch and switch-box in the Kingsland modified system.

Group (2). In 1888 Lineff devised a system which was tried on an experimental line in London, and in which an underground conductor is lifted by an electromagnet carried by the car. But the first system of this class to be put into commercial operation was that of *Diatto*. In fact this system may be said to be the forerunner of the Lorain and other systems, which will presently be described.

The Diatto system*. The distinctive feature of this system is the use of an iron bolt floating in mercury which is immediately under

* The following information is extracted from *La Traction Électrique par Contacts superficials du Système Diatto*, by Ch. Julius, 1902.

the stud, and it is through the lifting of this bolt by the magnet on the car that contact is made. The system is in operation in Paris over about 30 kilometres of track.

Figure 126 is a cross-section of one half of the track taken through the centre of a contact box. In it is shewn an end view of the combined magnet and collecting shoe or skate. Figure 127 shews a portion

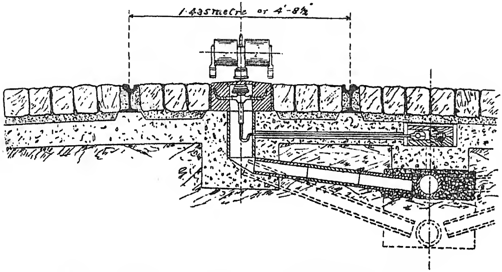


FIG. 126. Transverse section of track shewing skate, contact box, and feeder in the Diatto system.

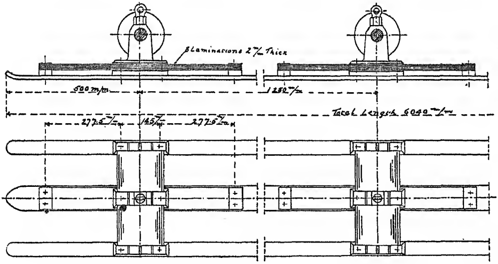


FIG. 127. Elevation and plan of skate collector in the Diatto system.

of the collector in elevation and plan. For a bogie car having 7·445 metres between bolster centres the skate carries five electromagnets spaced out at distances between centres of 1·25 metres. Each electromagnet has a centre pole terminating in the rubbing contact which collects current from the stud for the propulsion of the car. The two

windings on each magnet core set up opposing magneto-motive forces with the result that the two outside bars are magnetised similarly but of an opposite polarity to that of the rubbing contact bar at the centre. Starting from the pole at the centre the lines of force can be supposed to pass downwards through the surface contact stud, which is made of manganese steel and is non-magnetic, to a vertical iron bolt which floats in mercury. From thence they can pass horizontally along a circular iron plate through two embedded iron pieces projecting upwards to the outside poles of the skate. The bolt therefore endeavours to complete the magnetic circuit and in so doing rises in its bath of mercury, and makes the contact between the feeder cable and the surface contact stud. The block of insulation material which supports the contact box and surface contact stud is made of asphalte. The feeder cables run along the centre of the track and branch out on either side to the contact boxes, and the system is drained by the provision of earthenware pipes which pass from the bottom of the box cavity to a drainage duct at the centre of the track.

The **contact box** is illustrated in figure 128. The iron bolt A carries at its upper end a circular carbon contact B which normally rests upon the upper end of a nickel tube C, which contains the mercury in which the iron bolt A floats. The tube C is supported by a closely fitting tube D of ambroine which insulates it. The upper carbon contact E is supported by a metal box F which is fixed to the ambroine tube by a gasket ring G. A layer of paper is placed between the abutting surfaces to make the joint watertight. The joint at the top of the box is made watertight by a packing ring of rubber inserted in the metal ring which supports the carbon contact E and serves to hold the contact plate H in position. In order to prevent the blackening of the internal surfaces of the box due to the action of the electric arc, a shield I of crucible material is provided. It rests upon indiarubber pads and is secured in position by the box F pressing on its projecting lugs when the gasket ring is screwed up. The feeder cable terminates in a vertical direction and supports a metal mercury bath K, the height of which is so adjusted that when the contact box is placed in position the terminal L dips in the mercury and establishes contact between the feeder and the lower contact B. It is necessary to ensure that a good contact is made between the metal of the surface contact and the plate H. This is secured by aid of a coiled brass spring, concentric with the axis of the contact box, compressed between the under side of the ambroine tube D and the circular iron plate which is illustrated in figure 126.

The **excitation** of the skate magnet was originally provided by a compound winding, one coil of which was continuously traversed by a

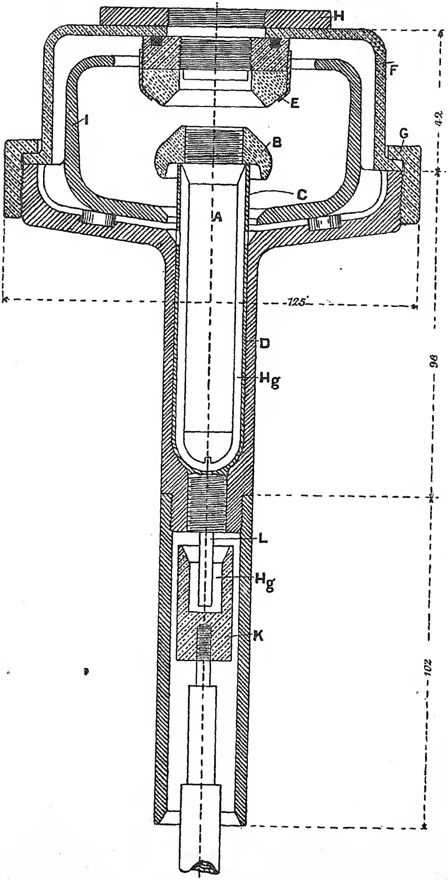


FIG. 128. Cross-section of contact box in Diatto system.

current from a storage battery carried by the car; the other coil being traversed by the current taken to the motors. The inconvenience caused by the charging of the battery has led to the present arrangement which allows of the battery being automatically charged by the motor current when this exceeds about 20 amperes. The magnetising coils are now placed in the direct circuit to the motors through an adjustable resistance, the magnetising coils having one end attached to the skate. The resistance of the magnetising coils is 0·6 ohm, and the adjustable resistance is usually about 0·2 ohm. The battery consists of eight storage cells having a 150 ampere-hour capacity and is so placed that it forms one of two parallel circuits; the other circuit being the magnetising coils of the skate, and adjustable resistance of about 0·2 ohm which is in series with them. With this adjustment of resistances, the battery discharges a current when the car is at rest of about 20 amperes through the magnetising coils and extra resistance. During propulsion of the car the current taken by the motors charges the battery when it has a value greater than about 20 amperes. It is found under these circumstances that the battery only requires an independent charge every two or three days. Each magnet winding has 3760 ampere-turns when traversed by a current of 20 amperes, and is enclosed in a zinc cover. In order that the centre bar of the skate shall be as uniformly magnetised as is necessary, the centre pole of each magnet is connected to a bridge piece consisting of eight iron laminations each 2 mm. thick, and this helps to distribute the magnetism more uniformly than would be the case if the pole were fixed directly to the rubbing bar. The two outside bars are directly connected to the polar extensions.

In the **combined surface-contact and trolley system** at Paris it is necessary to raise the skate when changing over to the trolley system. The skate is supported by a frame from which it is insulated and which is capable of being raised or lowered by spur gearing. In addition a two-way switch is operated, and this disconnects the motor circuits from the skate and connects them to the overhead trolley.

The **Lorain system*** has been in operation at Wolverhampton since February 6, 1902, and, fortunately, accurate data with regard to its working are available. Like other systems of its class it employs a combined skate and magnet for conducting the electric current to the motors and for making the required underground connection when the car is over a contact stud. With wheel bases of 6 feet to 6½ feet the

* The authors are indebted to Mr Wetmore of the Lorain Co. for information supplied in connection with this system.

studs are about 10 feet apart. Where the distance between the bolster centres of bogie cars is from 12 to 20 feet, the distance may be increased to 16 or even 20 feet.

A general view of the combined magnet and collecting shoe is given in plan and elevation in figure 129; and figure 130 is a transverse section of the track taken through the shoe collector and the centre of a contact box. Each skate has six electromagnets magnetised by series and shunt coils, which are enclosed in watertight castings. Each magnet circuit when over a contact box consists of the yoke KK, soft iron cores CC′, pole pieces FF′, the iron cover LL′, an armature AA and intervening air spaces. The yoke KK is firmly bolted to a transverse wooden beam fixed to the car undertruck. The pole pieces of the electromagnets are arranged in parallel lines with a small air space

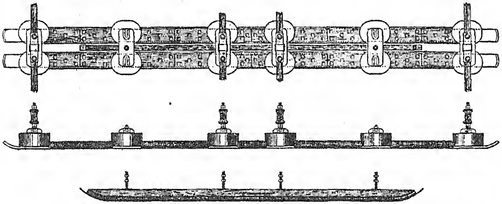


FIG. 129. Plan and elevation of Lorain skate collector and magnet.

between each. So long, therefore, as these poles are over a contact box the space SS′ is strongly magnetised and the armature AA is lifted against the force of gravity. The magnet poles FF′ are enamelled to prevent rusting. The skate or collecting shoe is shewn at H in figure 130 and is supported by a piece of rubber and linen hose R which is fixed to the longitudinal wooden beam B bolted to the yokes KK. The shoe is made of phosphor-bronze $\frac{1}{2}'' \times \frac{3}{16}''$ in section, and has a length of 12 feet when the contact boxes are 10 feet apart in order that the collection of current may be continuous. The poles FF′ in this case have a total length of 16 feet and therefore project 2 feet beyond the shoe at each end. This is to provide that connection may be made within the contact box before the shoe touches a stud, and also that contact may still be maintained for a short time after the shoe has left the stud. In this way arcing between the contacts in the boxes is avoided. With a margin of 2 feet at each end the time of operation of the contact allows of a speed of about 20 miles an hour.

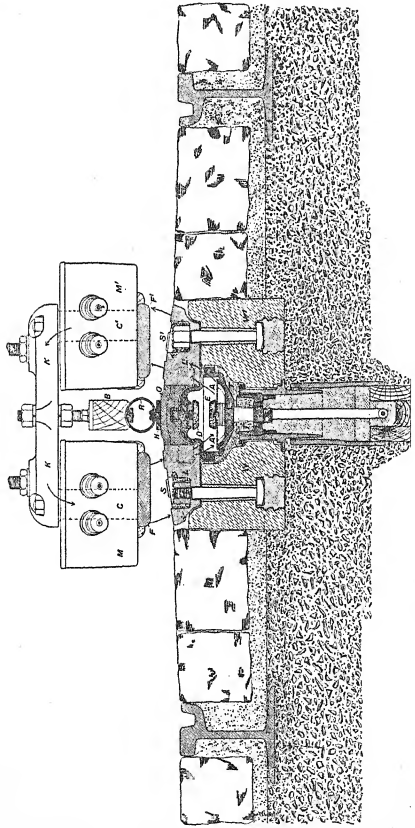


FIG. 130. Transverse section of track shewing skate magnet and contact box in Lorain system.

The **contact box**, shewn to a larger scale in section in figure 131, is the vital part of the system. This may be readily understood when it is considered that there are perhaps 528 to the mile of single track. Moreover it is by paying attention to small details of its construction that the maintenance costs have been reduced.

The box consists of a base of reconstructed granite WW′ (fig. 130) with an iron cover LL′ fitting into a recess. It will be noticed that the

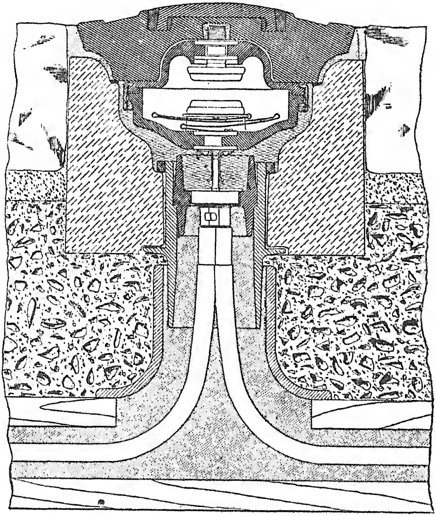


FIG. 131. Section of contact box in Lorain system.

cover is so constructed as to flange over the base and almost come into contact with the granite setts. Originally this was not so, as the recess was such as to allow of the granite coming level with the roadway. It was found that the granite got broken away in time and this led to the present construction. The cover is 15″ × $9\frac{3}{4}$″ and is held in place by two bolts and nuts, on the removal of which the contact apparatus may be withdrawn. The cover consists of four pieces, two of which,

LL′, are made of iron and become magnetised as above described. The centre piece is of manganese steel, and is non-magnetic. It is provided with a cap O of the same material, secured by spelter without bolts and nuts. Manganese steel is very hard, and is largely used at the present time for special work where severe wear and tear takes place. It is claimed that this removeable centre O will last from four to six years with a five minute car service, and it is easily renewed at small cost. It is well rounded off and projects about $\frac{3}{4}''$ above the paving. The area of the stud is 89 sq. ins., of which $27\frac{1}{2}$ sq. ins. is non-magnetic.

Directly under the cover LL′ is placed a circular box made of vulcabeston. The box is in halves with flanges which are firmly held together by means of an external brass screw-ring and gasket. The upper half supports the contact D and the lower half supports the armature A to which is attached the lower contact E. The contacts DE are circular discs of hard carbon about $\frac{3}{8}''$ thick and 2″ diameter around which are spun the brass supports. The maximum distance between the contacts is a full inch, as it is found that a $\frac{3}{4}''$ gap is only safe to deal with currents of about 20 amps. The armature AA is of soft iron $4\frac{3}{4}''$ long, 2″ wide, and about $\frac{1}{16}''$ thick, and is connected to the lower brass terminal of the cap by hard rolled copper strip folded upon itself. This is well shewn in figure 131, which gives a longitudinal section of the box. In recent construction the strip is fixed so that its length coincides with that of the armature. This is done to counteract the tendency of the magnetic field to produce side flashing between the upper contact D and the edge of the copper strip. The armature AA when acted upon by the magnetic field, that is when a car is over the stud, is lifted and establishes a contact between D and E. The copper strip not only serves to conduct the electric current but acts as a guide for the armature during its movement.

The cable which supplies current to the contacts is laid at Wolverhampton on the Callendar solid system, that is to say the trough is filled up solid with bitumen. The cable is looped in and its ends are fixed to a casting having an extension or tongue which serves to connect it with the lower terminal of the switch. On removing the box therefore a sliding contact is broken after the manner of a knife-edge switch. It will be seen therefore that it is of vital importance to thoroughly insulate the terminal piece attached to the cable, that is to stop any leakage between it and the road surface, as the rails on a 3′ 6″ gauge, as at Wolverhampton, are not more than 12″ away from the edge of the studs. The bitumen is filled in solid to the lower side of the casting which forms the cable terminal, and above it and around the vulcabeston cup in the space TT is poured a heavy oil which

causes any moisture to keep at the surface of the roadway. It will be noticed that the nuts used for holding down the casting LL′ are longer than usual. The top of the bolt is purposely left below the level of the top of the nut and allows of a space in which the oil can be kept. In this way the nuts never rust on to the bolts. The oil does not gradually mix with the bitumen.

The diagram in figure 132 shews how surface contact and overhead systems can be combined, and the manner in which the series and shunt coils used for exciting the picking up magnets are connected to the other parts of the wiring system of a car. The collector shoe is in contact with a stud which can be supposed to be in metallic contact

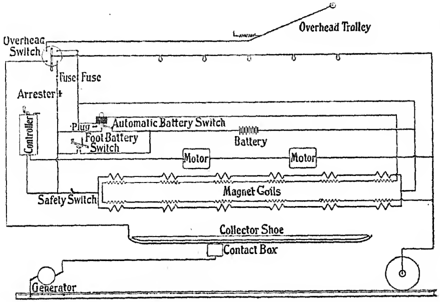


FIG. 132. Diagram of connections for combined trolley and surface contact system. (Lorain.)

with the underground feeder, *i.e.* with the positive pole of the generator. Current can pass to the overhead switch which will be so placed as to insulate the trolley. It now has three parallel paths open to it:

(1) It can pass through the lighting circuit; (2) it can pass through the shunt circuit of the picking up magnets; (3) it can pass through the series circuit of the picking up magnets, the controller, and the motors to earth. A battery of eight storage cells of 40 ampere hours capacity can be placed in parallel with the series coils of the picking up magnets in one of two ways, (*a*) should the line voltage drop sufficiently the diminished shunt current automatically operates the battery switch; (*b*) a foot battery switch can be operated by the driver. The cells are ordinarily used for starting the car from the

depot, or in case the line current has failed temporarily. It is not necessary to remove the cells for charging.

The Lorain equipment adds from 18 to 19 per cent. to the ordinary weight of a tram car.

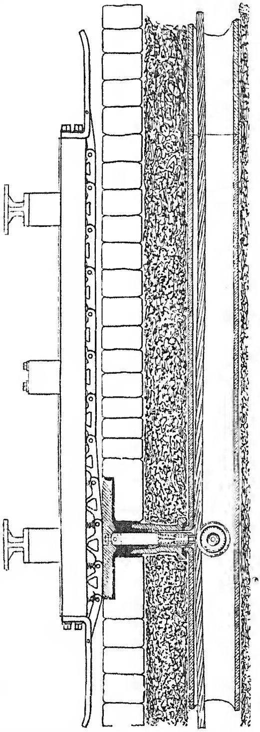


FIG. 133. Griffiths-Bedell skate collector.

The cables for a double track are on the ordinary distributor system. At every 100 to 200 yards four distributors, each of ·05 sq. in.

sectional area emanate from an ordinary feeder pillar supplied with fuses, and are looped in the boxes as shewn in figure 131. Suppose there are 30 boxes in a single track between two adjacent pillars, then 15 boxes would be connected to each pillar respectively. In this way it is easy to isolate a section of 15 boxes at one time.

The Griffiths-Bedell (G.B.) system has been installed at Lincoln over a distance of about 3 miles.

The **skate** of which there are two on each car is shewn in figure 133, and consists of three transverse parallel iron cores supported by the steel underframe, from which they are insulated and bridged across at their respective ends by two iron yokes. The yokes are parallel with the rails and one of them comes immediately over the contact studs. It is in the construction of this central yoke that we find one of the special features of the system. Instead of allowing the whole skate to trail over the studs as is usual the main portion is fixed about 2″ above the crown of the track and is provided with a longitudinal groove in which a flexible chain is placed. The chain is supported in position against the bottom of the groove by springs attached to the junctions of the links, and is then 2″ above the contact studs. When however the magnet is magnetised and the skate is over a stud the chain is immediately attracted to the stud, and establishes a sliding contact. As soon as the skate has moved away from the stud the chain is supposed to be drawn back into position and clear of the roadway. It is doubtful if this is actually the case when the car is running at high speeds. The advantage sought for is that the studs need not stand above the level of the road as is usual, and consequently the track is better suited for ordinary traffic. The second skate ensures that contact is made with one stud before breaking with its neighbour. The electromagnet can be excited either by a battery of six storage cells, or by current from the underground conductor. The battery connections are so arranged that it can be charged by line current. For starting purposes and until current is once established with the underground main the battery must be used. The magnet coil absorbs about 300 watts.

The **stalk and switch piece** which are shewn in figure 134 are at all times in metallic contact with the cast iron stud head, and are placed vertically downwards through a granite sett over openings in an underground stoneware pipe which runs the whole length of the track and contains the working conductor. The stalk is made of cast iron with a fork or slot at the bottom in which the switch piece works. The latter is built of laminated stampings, and supports at its lower extremity a carbon block which during

operation makes contact with the bare conductor underneath it. A bolt fixed across the fork and passing through a slotted hole in the switch piece serves as a guide for the latter during movement. Normally the switch piece is held up by a copper-coated steel spring which is insulated from the contact piece in order that it may not be damaged by the passage of electric current. The conduction of current takes place through two flexible copper conductors fixed between the

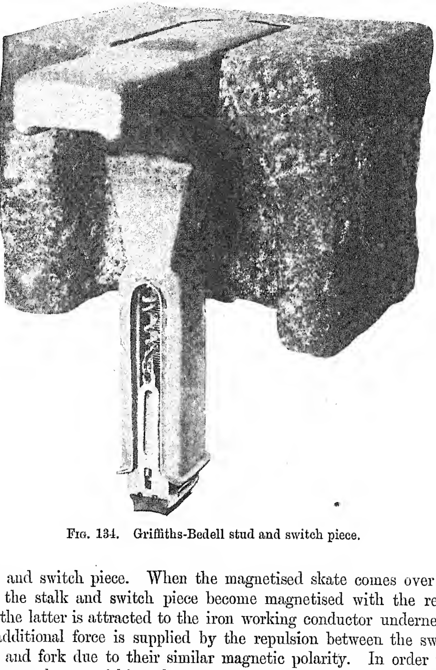


FIG. 134. Griffiths-Bedell stud and switch piece.

stalk and switch piece. When the magnetised skate comes over the stud the stalk and switch piece become magnetised with the result that the latter is attracted to the iron working conductor underneath. An additional force is supplied by the repulsion between the switch piece and fork due to their similar magnetic polarity. In order that there may be no sticking the fork is provided on its inner surfaces with copper liners. The stalk, where it passes through the granite sett

and a portion of the earthenware pipe connecting the sett with the longitudinal pipe, is insulated with bitumen. The distance between the top of the stud-head and the lowest point of the underground pipe is 19 inches.

The **conductor** from which current is taken to operate the car is at 500 volts above earth potential and is supported upon a series of circular porcelain insulators opposite each contact piece. The distance between centres is about 7 feet, and the insulators are supported by a metal rod passing through a hole in the side of the pipe. The rods are purposely put to earth by aid of external longitudinal iron strips which connect a number of them together. Any moisture which may condense on the surface of the insulators is carried under the action of electric osmosis to earth since the negative pole of the system is at earth potential. The working conductor is from this standpoint kept well insulated. Moreover it is obvious that any leakage current there may be cannot operate the contact or switch piece. Again if a stud were left alive a short-circuiting device carried by the car would cause an automatic cut-out to break the motor circuit. The working conductor is divided into sections connected respectively through feeders to the main or sub-station, each one including an automatic circuit breaker in its circuit.

In actual working at Lincoln it has been found that the action of the road mud on the pivots of the flexible skate produces excessive wear. This has been remedied by dispensing altogether with the joints as shewn in the illustration, and substituting a flexible steel cable from which all the links of the chain are hung. The action of the springs is not altered in any way.

In places where two tracks cross, unless precautions are taken to prevent it, the skate would be attracted to rails where they pass the centre of the track on which the car is travelling. This would, of course, earth the supply. To overcome this difficulty special lengths of manganese steel rails are inserted at these points. This material having a high percentage of manganese is not sufficiently magnetic to affect the skate.

The Dolter system is being or about to be tried at Torquay, Mexborough, Swinton and Rawmarsh, Hastings, Folkestone and Oxford and from 3 to 4 kilometers are installed near Paris. The studs in this system have each two surface contacts, with a view to ensuring a short and well-closed magnetic circuit. The contact box is illustrated in figure 135 and contains the contact-making device. This consists of a bell-crank lever the horizontal portion of which is of iron, and is attracted in an upward direction when the magnet carried

by the car passes over the box. A contact is thereby established between two carbon blocks, the one on the end of the bell-crank lever and the other fixed to the wall of the contact box and connected to the underground feeder. In this way current can pass from the underground feeder via the bell-crank lever to the stud on the road surface, and from thence to the motors via the skate collector. The magnetised skate is attached to the car by globe insulators and turnbuckles. By

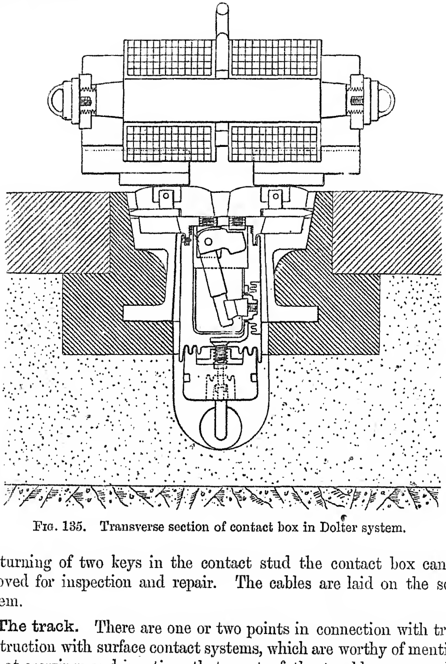


FIG. 135. Transverse section of contact box in Dolter system.

the turning of two keys in the contact stud the contact box can be removed for inspection and repair. The cables are laid on the solid system.

The track. There are one or two points in connection with track construction with surface contact systems, which are worthy of mention. It is at crossings and junctions that most of the trouble occurs. For instance where one track crosses another the skate must either be raised to clear the transverse rails, or the rails themselves must be

insulated. At Wolverhampton the rails are not insulated, and reliance is put on the skate being raised sufficiently to clear the rails. The distance of the nearest stud from these sections may be 4 inches, but it is not desirable to have them nearer on account of the leakage between the stud and the rail when the former is alive, and the liability for short circuits. It has been proposed to have dummy studs where the rail is uninsulated and when the studs are so near to the rail, but this would mean coasting over such places, and would cause a flicker in the car lighting. The insulation of the intervening rails presents considerable difficulty. Figure 136 shews how it has been carried out in Paris. It will be seen that the track to be insulated has four insulation spaces between the two transverse rails. In this way double insulation is obtained between the centre piece and the earthed terminal of the system.

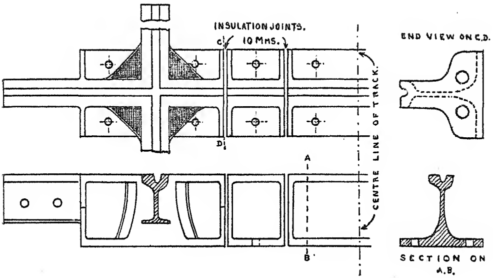


FIG. 136. Insulated rail sections in Diatto's system in Paris.

The liability to short circuit at crossings and the disastrous results caused thereby, have led to the insertion at the pillar box of a resistance of 2 ohms in series with each of the cables. A short circuit can then only cause a current of about 200 amperes to flow. The short circuits at Wolverhampton, as pointed out by Mr Shawfield, have generally arisen from scrap-iron falling on to the track. Excessive currents, if they do not completely ruin the box, blacken its interior surface by burning and by carbon deposited from the contacts. The latest device is to place automatic cut-outs in the pillar boxes, which close the circuit at a predetermined interval of time after the short circuit. In this way the circuit is again made after allowing a reasonable time for the removal of the obstacle. Fig. 137 shews the arrangement of rails and surface contacts in the Diatto system at Paris.

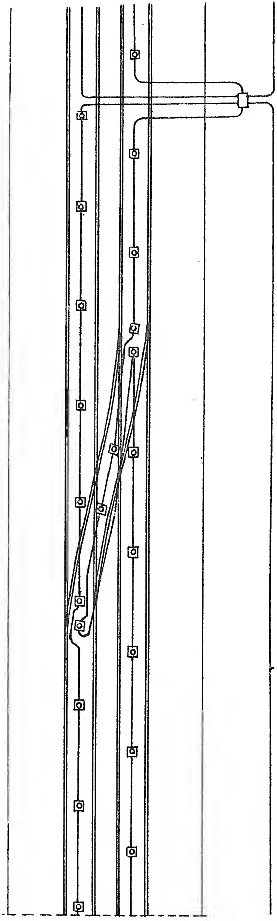


Fig. 137. Arrangement of cables and surface contacts at a cross-over in Diatto's system.

Group (3). The greatest ingenuity has been spent upon electromagnetic devices for operating underground contacts as the car passes over the studs.

The Claret-Viulleumier system deserves special mention inasmuch as it was one of the first surface contact systems to be installed. It was laid down in Paris in 1896, after being experimented upon in Lyons in 1894, and is still in operation in Paris over a distance of about four miles. Instead of employing an electromagnetic switch for each contact stud at the road surface, as has been the case in most other systems, a series of "distributors" are arranged along the track at intervals of about 300 ft., each distributor controlling the supply of energy to a group of contacts equal in number to those between two adjacent distributors. The distributor is in reality a switch which automatically connects the contacts under the car to the main feeder. The switch is turned by the aid of a pawl and ratchet wheel, and the lever carrying the pawl is moved to and fro by electromagnets which are alternately magnetised by currents from the studs. Should the distributor fail to act and the car move forward in virtue of its momentum, the studs might be left alive. To obviate this an additional skate, known as the *short circuiting skate*, is sometimes carried by the car and connects all the studs in turn with the frame, that is with the earth return. This is a device not peculiar to this system, and is employed on others. In addition there is always the liability of a following car running on to a section still occupied. In this case the car cannot obtain current until the section is cleared, and then the distributor has to be turned until the studs under the particular car are alive.

The Schuckert and the Wheless systems have been successfully operated at Munich and Washington respectively. They differ from the Claret-Viulleumier system in that each stud has its own electromagnetic switch placed immediately underneath it.

CHAPTER 9.

FEEDER SYSTEMS FOR TRAMWAYS; POSITIVE, NEGATIVE AND AUXILIARY CABLES.

In the term "feeder system," as here used, are included all the conductors which form the electrical circuit with the exception of the trolley wires and rails.

It will be best to consider these conductors under three headings, viz. the positive, the negative and the auxiliary system.

(*a*) The positive system comprises all the cables which take the current from the generating or sub-station to the trolley wires, and those, if any, which are connected in parallel with these wires.

(*b*) The negative system comprises all the cables which join up the rails to the negative bus-bars.

(*c*) The auxiliary system includes cables laid down for telephones and for testing the potential difference between various points. These are not in reality feeders; but it is convenient to include them with the power cables.

General Considerations. The design of the feeding system for any particular tramway is based upon several considerations, chief among which are the following:

(*a*) As concerns the positive system:

1. The Board of Trade requires that the voltage in the generating or sub-station shall not exceed 650 volts, and that the voltage on the trolley wires shall not exceed 550 volts. (See B. T. Regs. p. 450.)
2. The Board of Trade requires that the trolley line shall be divided into sections not exceeding half-a-mile in length, such sections being connected through switches which can be opened in case of emergency. (See B. T. Regs. p. 445.)

(*b*) As concerns the negative system.

3. The Board of Trade requires that the current in any single rail shall not exceed 9 amperes per square inch of cross-section. (See B. T. Regs. p. 445.)
4. The Board of Trade requires that the potential difference between any two points of the rail system shall not exceed 7 volts. (See B. T. Regs. p. 445.)

As applying to the feeder system in general.

5. Considerations of practical working require that any failure in the trolley wire or one of the feeders shall produce as little disturbance as possible in the operation of the tramway system.
6. Considerations of economy require that the efficiency of the feeder system should be taken into account with the efficiency of the operation of the cars.

Of these requirements, the first four need no comment. With regard to the fifth, it may be said that it is customary to divide the trolley wire system into a number of isolated sections fed direct from the generating stations by separate feeders. These sections are of varying lengths according to circumstances, the average being perhaps two miles. Arrangements must also be made for feeding each section from neighbouring sections in the event of the feeder breaking down.

With regard to the sixth requirement, there are two points to be considered, the current density in the cables, and the drop of potential at the far end. Economical working of the motors necessitates a limit to the drop and it may be taken approximately that on a 500 volt system the voltage at the cars should not fall below 450 or rise above 550. Economical working of the cables deals more with the root-mean-square currents passing through them, the general principle being that expressed by Kelvin's well-known law that the annual expenditure on the cables should be a minimum. This expenditure includes the cost of energy lost in the cables, and the annual charge for interest and depreciation. These two points considered together will settle the sizes of the various feeders.

Most economical size of feeder cable. In estimating the most economical size of cable wherewith to transmit current, the following data are necessary:

Price per kilowatt hour (including works cost and charges for interest and depreciation on the generating plant) about 0·6*d.*

*Price per mile of low tension paper insulated lead covered cable laid and jointed, about £1500 per sq. in. of cross-section.

* This price varies, naturally, from time to time, with the price of raw materials, and does not include the cost of excavation, reinstatement, &c., which is approximately an additional fixed charge roughly independent of the size of the cable.

The most economical size must be so chosen that the interest and depreciation plus the annual cost of energy lost in the cable is a minimum. Taking $4\frac{1}{2}$ per cent. for interest and $2\frac{1}{2}$ per cent. for depreciation, the annual charge on a mile of 1 sq. in. cable will be $\frac{7}{100} \times 1500 = £105$. To calculate the annual charge for energy lost, suppose the full current to flow for an average time of 15 hours per day all the year round, *i.e.* for 15×365 hours per year $= 5500$ say. If then the 1 sq. in. cable carries 420 amperes, the power lost will be the current multiplied by the volts, *i.e.* 420×18 watts per mile, or the annual loss will be $\frac{420 \times 18}{1000} \times 5500 = 41500$ units. The cost of this at $0{\cdot}6d.$ per unit will be £104. These two amounts are very nearly equal, which is the condition that their sum should be a minimum. Reckoned in this approximate way, therefore, it appears that the most economical size of feeders is such that the working current is transmitted at a density of about 420 amperes per square inch.

Alternative consideration of economy. Objection may be taken to the above method of calculating the most economical size of cable on the grounds of a mistaken estimate of the cost of the energy wasted in the cable. Thus it may be argued that although the average cost per kilowatt hour may be $0{\cdot}6d.$, yet in any particular case if the sizes of all the feeder cables were halved the expenditure on energy dissipated would not by any means rise in proportion to the increase of the losses.

Take, for instance, a table of works cost, samples of which are given in Chapter 22 of this volume. Suppose the analysis is as follows:

Fuel	·26*d.*
Oil, waste, stores, and water	·03*d.*
Wages and salaries	·09*d.*
Repairs and maintenance	·08*d.*

Of these items, it would be contended that the last two would be unaffected by any slight increase in the output, in other words that the cost of energy should be taken as a fixed sum plus a variable. With the above figures the variable part would be only ·29 pence per unit.

In applying Kelvin's law, it is necessary only to take account of the variable portions of the two sets of costs. Thus, on the above reckoning, taking as before £105 as the interest and maintenance on 1 mile of 1 sq. inch cable, a current density of 600 amperes per square inch would be most economical; thus,

$$\frac{600 \times 25{\cdot}8}{1000} \times 5500 \times \frac{\cdot 29}{240} = £103.$$

These two different points of view will commend themselves variously to different engineers.

Simple case. Before going into the general design of a complete feeder system, it will be best to examine several points that occur in a simple case such as a straight road with no branches.

Consider first the calculation of the maximum drop. This obviously depends upon the maximum current per car, and upon the number of cars. Now the average current for a car equipped with two 35 H.P. motors is generally about 20 amperes and the maximum about 150 amperes; with an equipment of two 25 H.P. motors the currents are generally about 14 and 100 respectively.

The estimation of the maximum drop at the end of a line when there are a number of cars distributed along it, is not easy. The following method is suggested.

Suppose the cars equally spaced, starting from the far end; then the worst case may be assumed to be as shewn in Table 16.

TABLE 16. *Values of current in equal lengths of trolley wire corresponding to maximum drop at the far end.*

Division of trolley wire	Average current per car 14	17	20	Ratio maximum / average
1	105	128	150	7·5
2	147	179	210	5·25
3	154	187	220	3·67
4	161	195	230	2·87
5	165	200	235	2·35
6	168	204	240	2·0
7	173	210	246	1·76
8	178	215	252	1·58
9	183	222	260	1·45
10	189	229	270	1·35
11	196	238	279	1·27
12	202	245	288	1·20
13	210	254	300	1·15
14	219	266	315	1·12
15	229	278	328	1·09
16	240	290	342	1·07
17	252	305	361	1·06
18	264	320	380	1·05
19	278	338	399	1·05
20	294	356	418	1·05

These currents are not, of course, the maximum values in each section, but are intended to be the values occurring at the moment

when there is a maximum drop at the far end. From this table, a fresh table can be made out shewing the equivalent maximum current along the whole length for different numbers of cars, *i.e.* the current which, flowing along the whole length, would give rise to the maximum drop at the end.

TABLE 17. *Equivalent maximum current for various distributions of tramcars.*

Number of cars	Average current per car 14	17	20	Ratio Equiv. max. / average
1	105	128	150	7·5
2	126	154	180	4·5
3	139	165	193	3·22
4	142	172	202	2·53
5	146	178	209	2·09
6	150	182	214	1·78
7	153	186	219	1·56
8	156	190	223	1·43
9	159	194	227	1·26
10	162	197	231	1·15
11	165	201	235	1·07
12	169	204	240	1·00
14	175	212	250	·89
16	182	221	260	·81
18	191	231	272	·75
20	200	243	286	·71
30	250	304	358	·60

Thus, supposing there are 10 cars on a stretch of road each taking an average current of 18 amperes, the maximum drop will be the same as if a current of $1{\cdot}15 \times 18 \times 10 = 207$ amperes were flowing along the whole length. This factor thus provides a quick method of estimating the maximum drop in the trolley wire.

Strictly speaking, this method is not applicable to a double track, but in most cases the error introduced by supposing the two trolley wires to be in parallel along the whole length instead of being connected only at half mile intervals is not very serious. In any case the calculation is only approximate, and it is doubtful whether anything more elaborate is worth while. As applying to the rails of a double track it is more nearly accurate owing to the frequent cross bonding.

Density of traffic. To facilitate calculations for feeder systems it is useful to be able to tell at a glance the density of the traffic or the number of cars per mile for various headways and various average speeds. Table 18 gives this information.

TABLE 18. *Number of cars per mile of single track for different speeds and services.*

Average speed miles per hour	6	7	8	9	10	12	14
Service							
$\frac{1}{2}$ minute	20	17·1	15	13·3	12	10	8·5
$\frac{2}{3}$ „	15	12·9	11·2	10	9	7·5	6·4
1 „	10	8·6	7·5	6·7	6	5	4·3
$1\frac{1}{3}$ minutes	7·5	6·4	5·6	5	4·5	3·75	3·2
$1\frac{1}{2}$ „	6·67	5·7	5	4·44	4	3·33	2·85
$1\frac{2}{3}$ „	6	5·1	4·5	4	3·6	3	2·6
2 „	5	4·3	3·75	3·33	3	2·5	2·14
$2\frac{1}{2}$ „	4	3·4	3	2·66	2·4	2	1·7
3 „	3·33	2·86	2·5	2·22	2	1·66	1·43
4 „	2·5	2·14	1·87	1·67	1·5	1·25	1·07
5 „	2	1·71	1·5	1·33	1·2	1	·86
7 „	1·43	1·23	1·07	·95	·86	·71	·61
10 „	1	·86	·75	·67	·6	·5	·43
15 „	·67	·57	·5	·45	·4	·33	·28

Example. To illustrate the use of this method of calculating voltage drops, and in order to introduce the question of feeders in a simple system, take the case of a tramway consisting of a length of 6 miles of double track with the generating station at the centre.

Particulars:

Length of double track	6 miles.
Service of cars in both directions	$1\frac{1}{2}$ minutes.
Average speed	8 miles per hour.
Size of trolley wire	0000 L.S.G.
Resistance per mile of two trolley wires in parallel	·175 ohm.
Weight of rails	100 lbs. per yard.
Resistance of double track per mile $= 12 \times \frac{\cdot 043}{4 \times 10}$ + say 10 per cent. for bonds	·0142 ohm.
Car equipments	two 30 H.P. motors.

From these particulars the maximum drops can be calculated as follows:

Number of cars per mile of double track	10
Number of cars between generating station and far end of line	30
Equivalent maximum current $\cdot 6 \times 17 \times 30$	306 amps.

Maximum drop at far end:

$$\text{Positive } 306 \times \cdot 175 \times 3 = 160 \text{ volts}$$
$$\text{Negative } 306 \times \cdot 0142 \times 3 = 13 \text{ volts.}$$

It is, therefore, immediately evident that a feeder system is required to reduce both positive and negative drops.

Positive feeders. As already pointed out, the positive feeders fulfil the duty of supplying the various sections of the line with current at a suitable voltage. In the case of a breakdown on any portion of the system, as for instance when a trolley wire falls on to the track, it is very important that current should be cut off and that the accident should not affect a large portion of the system. To provide for this it is customary to divide the whole system of trolley wires into a number of divisions, each one insulated from all the others. Each of these divisions is supplied by a separate positive feeder from the positive bus-bar in the generating station, through an automatic cut-out on the switch-board. By this means the distribution of energy to the various parts of the system is under the control of the switch-board attendant. The Board of Trade requires that the trolley wire shall be divided up into sections not more than half a mile long, the sections being connected through switches in the section pillars. By keeping some of these switches open the line is divided into a number of insulated portions as required.

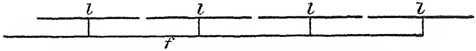


FIG. 138. Diagram of the connections of a parallel feeder to the insulated sections of trolley wire.

Assuming, then, that suitable divisions of the line have been chosen, it remains to consider the best method of arranging the feeders. Several ways are possible but some are better than others.

In the first place it is possible to keep all the section switches open and feed into the centre of each section from a parallel feeder, as shewn in figure 138, in which *ll* is the trolley line cut up into insulated half-mile lengths and *f* is a parallel feeder connected every half mile to the trolley wire. The chief advantage of this method lies in the fact that in order to cut off current from any section a man has not more than a quarter of a mile to go. It possesses a great drawback, however, in that the trolley wire is used only as a distributor and takes no part in carrying the current to sections remote from the generating stations. For this reason it is very wasteful in copper.

A second method is to make the divisions of such a length that if the feeding point is in the middle the drop at each end does not exceed a reasonable amount. Thus figure 139 represents three miles of trolley wire *ll* with the feeding point in the middle.

A third method is to feed in to a division at the end nearest the generating station and supplement the trolley wire by means of a parallel feeder or distributor. Figure 140 shews this arrangement, wherein *ll* is the trolley wire, *f* the feeder and *d* the distributor.

The disadvantage of the first method has been pointed out already. The second method certainly utilises the trolley wires for conveying the current to the ends of the division, but it will be apparent that the path of the current is not the most economical. For consider the current supplied from the generating station to the nearest end of the division. This current has to go first to the feeding point and then back again to the car. Thus if the division is 3 miles long and the feeding point 4 miles distant from the generating station, the path of the current is $5\frac{1}{2}$ miles long in order to reach a point only $2\frac{1}{2}$ miles away. In this respect the third method is better; and it possesses the further advantage that the section of the distributor can be graduated,

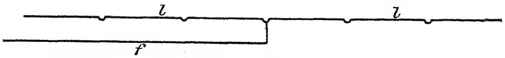


FIG. 139. Alternative method of connection of trolley wire and feeder.

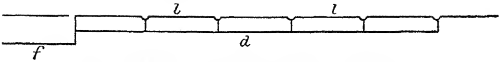


FIG. 140. Method of connection of trolley wire and feeders using a parallel distributor.

so that as the distance from the generating station increases, the size of the distributor can be reduced in proportion to the number of cars to be supplied.

The third method is the one most usually adopted, and it is customary with this arrangement to take the distributor to the last half mile of each route, so that every length of trolley wire is connected to the feeding system. This provides ample security against breakdown, even though the distributor is not always justified for electrical reasons. Thus suppose figure 140 represents the far end of a certain route; the possibilities of breakdown are three; (1) the feeder *f* may be under repair, (2) a length of the distributor *d* may have to be cut out, (3) a length of trolley wire *l* may be down. In the first case, power can be supplied to the division at the feeding point by closing the section switches between this division and the next. This may overload the trolley wires and feeders of the neighbouring division; but it would most probably permit of the service being maintained although perhaps reduced to some extent. Some engineers would

prefer to supply duplicate feeders to each feeding point; but this is somewhat costly. In the second possibility of breakdown, the faulty length of distributors would be cut out by switches at the feeder pillars. In the third possibility, viz. when a length of trolley wire has to be cut out, current can be transmitted to the more remote sections through the distributor.

Negative feeders. The problem of the design of the negative feeder system presents itself in quite a different light. In all systems the track forms a single conductor in which, from the nature of the case, no electrical division is possible. As already stated, the negative feeders are required for the purpose of taking the current back to the generating station in such a way that the difference of potential between any two points of the rails shall not exceed 7 volts.

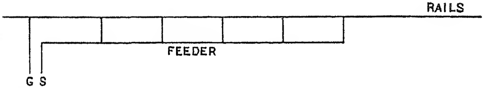


FIG. 141. Diagram of negative feeder connected to the rails at frequent intervals.

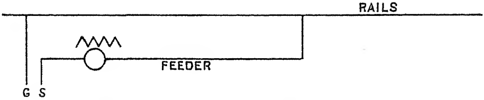


FIG. 142. Diagram of connection of negative feeder and negative booster.

In general, there may be said to be three different methods. The first method consists simply in supplementing the rails by means of one or more copper conductors, which carry part of the current, and so reduce the drop in the rails. In some cases this system is quite sufficient. It is shewn diagrammatically in figure 141.

In the second method, current is brought back from various parts of the system, chiefly the outlying parts, by means of special feeders combined with negative boosters, as shewn in figure 142. The booster is simply a series wound generator, so designed as to supply a voltage exactly equal to the drop in the feeder; the combination of feeder and booster is, therefore, equivalent to a resistanceless conductor (*i.e.* so far as drop is concerned), and the feeding point is kept constantly at the same potential as the negative bus-bar. (For the excitation of the booster see below.)

The third method, as shewn in figure 143, consists in laying several negative feeders from the generating station to various feeding points, the sections of the cables being so adjusted that the drop in each feeder is the same. In this case the rails are not at the same potential as the bus-bars, but this is unimportant provided the requirements as to the 7 volt drop are satisfied.

Of these three methods there is no *à priori* reason for adopting one to the exclusion of the others in every case. In some systems one method is superior, in others another method.

Negative boosters. Before applying the above methods of designing positive and negative feeders to a particular case it will be desirable to consider the negative booster.

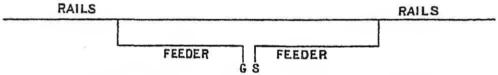


FIG. 143. Diagram of negative feeders in which the negative bus-bar is not at earth potential.

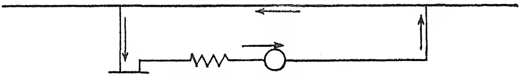


FIG. 144. Diagram shewing negative booster wrongly connected.

The idea with which this apparatus was first suggested was that it should be simply a series wound generator giving a terminal voltage exactly proportional to the current in the armature and field winding. If such a generator be connected to the feeder and the negative bus-bar as in figure 144, it will be apparent that the generator is working on a closed circuit of very low resistance, and a local circulating current will be set up quite independent of the supply to the cars.

To overcome this difficulty, it is customary to excite the booster by means of the positive or outgoing current of the same division. If, then, the booster is suitably wound it will act as a sucker, and will draw back through the feeder a current exactly equal to the outgoing current.

As to how far the booster really responds to the very rapidly fluctuating load, it is difficult to say. No doubt, it is possible to construct a machine that will follow precisely the variations of current; but it would require a laminated magnetic circuit, and a saturation curve which is practically a straight line.

Application of the above methods to a particular case. The calculations already made on p. 193 for the case of a simple system containing 6 miles of double track shewed that both positive and negative feeders were necessary.

For the positive feeders, a suitable division would be to cut the line into 4 equal lengths each consisting of 3 half mile sections. The two central divisions would be connected to the generating station

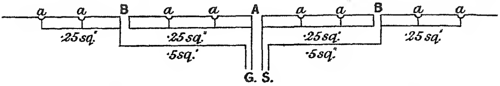


FIG. 145. Diagram of positive feeders and distributors for a typical case.

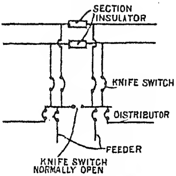


FIG. 146. Diagram of feeder pillar connections at point A in figure 145.

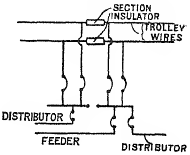


FIG. 147. Diagram of feeder pillar connections at point B in figure 145.

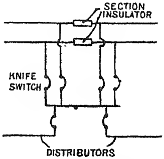


FIG. 148. Diagram of section or feeder pillar connections at the point *a* in figure 145.

by short feeders from the nearest points, and the outer divisions by feeders each $1\frac{1}{2}$ miles in length. The trolley wires would be supplemented by distributors as shewn in figure 145, the section and feeder pillars being shewn diagrammatically in figures 146, 147 and 148.

Suppose the sections of feeders and distributors to be as shewn in figure 145, viz. ·5 sq. inch feeders, and ·25 sq. inch distributors. The calculation of the positive drop to the far end will be as follows :

1. First half mile	
Equivalent maximum current	= 180 amps.
Drop in half mile = $\frac{1}{2} \times 180 \times \cdot175$	= **15·7 volts**
2. Between feeding point and last feeder pillar (1 mile), resistance per mile of two No. 0000 trolley wires in parallel with ·25 sq. inch distributor	·086 ohm
Average maximum current in the mile length (average of currents in lengths 6 to 15, Table 16)	236 amps.
Drop = $\cdot086 \times 236$	= **20·3 volts**
3. In $1\frac{1}{2}$ miles of feeder	
Resistance per mile of ·5 sq. inch feeder	·086 ohm
Effective current in feeder	290 amps.
Drop = $\cdot086 \times 290 \times 1\frac{1}{2}$	= **37·4 volts**
Therefore the maximum positive drop at the far end will be $15\cdot7 + 20\cdot3 + 37\cdot4$	= **73·4 volts**

For the negative feeder system, it will be obvious that the choice lies between the second and third of the methods described above.

The former of these will require a negative feeder to the point where the positive feeder is connected to the distributor and the trolley lines. Assuming a positive current of 290 amperes, and a negative current maintained exactly the same by means of the booster, the drop in the negative feeder with a ·5 sq. inch cable will be

$$290 \times 1\cdot5 \times \cdot086 \qquad = \textbf{37·4 volts}$$

and the booster must be so designed as to give this voltage with the above-mentioned current.

Taking the average current as $15 \times 17 = 255$ amperes, the average drop will be 33 volts, and the average output of the booster will be 255×33 watts $= 8\cdot4$ kw. With the alternative method no boosters would be used, but cables would be laid from the generating station to points in the rail return such that the drop between them and the ends of the line did not exceed 7 volts. Suppose, in order to allow a small margin, the drop is limited to 5·5 volts. Then the negative feeding point will be about 1·3 miles from the generating station. (Thus between this point and the end of the line there will be 17 cars spread over a length of 1·7 miles, and the drop will be $226 \times 1\cdot7 \times \cdot0143 = 5\cdot5$ volts.) The negative feeders will therefore be say two 1 sq. inch cables, each 1·3 miles in length, and the drop in each will be about $510 \times 1\cdot3 \times \cdot043$ volts $= 28\cdot4$ volts.

Comparing the two methods, it is obvious that in first cost as well as in efficiency the former has the advantage. The drop to the far end

with the first method will be 78 volts, and with the second method 107 volts; but these figures cannot, of course, be used to indicate the efficiency.

Efficiency of distribution. The average losses in the distribution system cannot be estimated with any great degree of accuracy. The average loss for each car will be approximately the product of the average current and the average drop *while the current is on*. The loss will vary a great deal at different points of the same system but a rough approximation can be made. In the case worked out above the voltage drop to the feeding points may be taken as approximately constant; and the mean drop from each feeding point to the far end of the corresponding division will be roughly about half the maximum. For the outer divisions the mean drop will be about as follows:

(Positive) from generating station to feeding point say	33 volts
,, from feeding point outwards	18 volts
(Negative) from negative bus-bar to feeding point $\frac{33}{\cdot 8}$ (assuming 80 per cent. efficiency of booster)	41 volts
,, from feeding point outwards	2·3 volts
Total	94·3 volts.

For the divisions nearer the generating station the drop will be approximately $18 + 2{\cdot}3 = 20{\cdot}3$.

Hence the mean drop may be taken as $\frac{1}{2}(94{\cdot}3 + 20{\cdot}3) = 57{\cdot}3$ volts, and the efficiency will be $\frac{550 - 57{\cdot}3}{550} = \mathbf{89{\cdot}6}$ per cent.

Tramway systems in general. Many of the considerations which have been discussed in connection with the simple case given above, apply equally to more extensive systems. As far as the radiating routes are concerned precisely the same method may be employed, and the results will only differ materially in that the service assumed is not probable on the more remote portions of a system. As a consequence, the divisions are likely to be longer than $1\frac{1}{2}$ miles.

Near the centres of large towns, however, the tramway routes generally converge, and traffic is very dense. In such places the maintenance of the various services is more important than the drop of potential, especially in those cases in which the generating station is near the centre and the drop of potential is likely to be small. Thus, for instance, at a place where two heavy streams of traffic cross, any interruption on one line will paralyse the traffic on both lines unless the crossing is isolated. In the crossing shewn diagrammatically in

figure 149, there may be twelve streams all of which make use of the junction. It is probably worth while to isolate completely the whole junction as shewn, and feed it by means of a separate cable.

Or, again, a certain street may form part of many different routes, in which case any breakdown would have very widespread effects. It is, therefore, essential to prevent as far as possible any accident on a neighbouring portion of line from affecting this particular portion simultaneously. This is secured by isolating the vital part, and arranging for separate feeding. An example of this is quoted in a paper on Electric Tramways by Messrs Hopkinson and Talbot* in their description of the feeder system at Leeds.

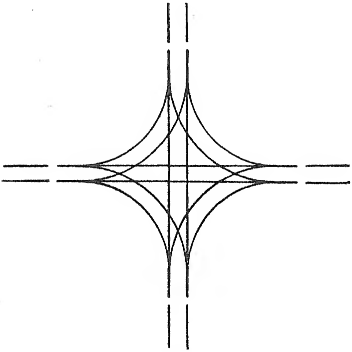


FIG. 149. Diagram of double track junction and crossing.

Apart from these special points, there are frequently other considerations applying to particular parts of any system which will require attention. For instance, in almost all important tramway installations, there are generally one or more places where the demand for accommodation rises occasionally far beyond the average. Such demands occur on public holidays or half-holidays, at the close of entertainments or athletic meetings. At such times, unless precautions are taken, the feeding arrangements are likely to break down. The means to be taken to guard against excessive overloads are various according to the circumstances of the case; it may be necessary to

* *Proc. Inst. Civil Engineers*, vol. 151.

instal sufficient cables to deal with the maximum demand, or it may be possible to switch over a feeder usually connected to another branch, so as to work it in parallel with the regular feeder on the overloaded line. Or, again, it may be that the existing cable will carry the current without overheating, but under conditions that would imply an excessive drop in the voltage. In such a case it may be worth while to instal a positive booster for occasional use with this feeder, so as to overcome the difficulty in the regulation; the question of economy of power being quite unimportant for so short a time.

Steep grades must, of course, be remembered, and allowed for in the initial design of the feeder system; but this is a matter of regular service and not of occasional occurrence.

Example of feeder system. A good example of a large tramway system is provided by the Belfast City Tramways, one of the most recent installations of electric tramways in large cities*.

This system, shewn in figure 150, contains 14 routes, chiefly radiating from the centre of the city, the services on the various routes being as follows:

A route, Belmont. 5 minutes service from City to Gelston's Corner, and 10 minutes beyond.

B route, Knock. 5 minutes service from City to Knock Depôt, and 10 minutes beyond.

C route, Woodstock Road. 5 minutes service from City to Ravenhill Avenue, and 10 minutes beyond.

D route, Ravenhill Road. 10 minutes service from City to terminus.

E route, Ormeau Road. 5 minutes service from City to terminus.

F route, Malone Road. $2\frac{1}{2}$ minutes service from City to Stranmillis Junction, and 5 minutes to end of route.

G route, Lisburne Road. 5 minutes service from City to terminus.

H route, Falls Road. 5 minutes service from City to Falls Park, and 10 minutes beyond.

K route, Springfield Road. 10 minutes service from City to terminus.

L route, Shankill Road. 5 minutes service from City to terminus.

M route, Crumlin Road. 5 minutes service from City to Ardoyne Junction, and 10 minutes beyond.

* The authors wish to express their thanks to Mr M'Cowan, the City Electrical Engineer, who has kindly supplied them with information as to the feeder system of the Belfast City Tramways.

N route, Antrim Road. $2\frac{1}{2}$ minutes service from City to terminus, 10 minutes service on Cliftonville Road.

O route, Shore Road. $2\frac{1}{2}$ minutes service from City to N. C. Railway, and 10 minutes beyond.

P route, Queen's Road. 5 minutes service from City to Co. Down Railway.

In the figure all these routes are clearly marked; the positive feeders are shewn in full lines and the distributors in dotted lines, the section of each cable being given. The lines are double track throughout, with a 4 ft. 9 in. gauge; the rails weigh 105 lbs. per yard, and the trolley wire is 0000 S.W.G. There are four negative feeders, one 1·5 sq. inches, two 2·5 sq. inches, and one 2 sq. inches, all cables being laid solid in earthenware troughs. The cars are double deck single truck cars, with an average speed of 8 miles an hour, and a maximum of 12 miles an hour. The connections in the feeder pillars are shewn in the drawing, being practically the same as in figures 146, 147 and 148.

Distribution by means of sub-stations. In the large majority of towns in this country a direct current distribution from a single power station is quite sufficient for the requirements of the tramway service. In a few cases, such as London and Glasgow, the system is so extensive that it becomes more economical to generate high tension alternating currents and transmit to sub-stations, from which low tension direct current is distributed to the trolley wires. Occasionally it is found desirable to adopt a mixed system, in which the large bulk of the supply is direct current low tension from the generating station, and one or more outlying parts are fed from a suitably placed sub-station. An example of such a system is found at Belfast (not shewn in figure 150).

No definite rules can be given as to the line to be drawn between the straightforward direct current generation and distribution and the alternating current sub-station system. In every case in which the question arises, the problem must be considered very carefully from several points of view. In the first place the initial outlay of the two systems must be compared. This will involve the working out of two more or less complete schemes and a fairly accurate knowledge of the cost of apparatus and buildings, of cables, excavation, etc., etc. In the second place a careful estimate must be made of the working expenses, and also a comparison of these with the interest and depreciation calculated from the initial outlay. In all probability one or both of these considerations will afford sufficient material on which to base a decision; but, if not, other points of view may be taken into account, such as simplicity of operation, reliability against breakdown, possibility of distribution of batteries, and so on. The question does not

often arise in tramway work, as in most cases the system is either so small or so large that there is practically no choice.

The distribution of energy to sub-stations. High tension distribution is carried out on very much the same lines as low tension distribution; but it will be more convenient to leave its consideration until the feeder system for direct current railways is discussed. The reader may be referred, however, to the account of the Glasgow Corporation Tramways as an instructive example of a system in which energy is transmitted to a number of sub-stations at high tension*.

Distribution to tramways worked on the conduit system. In the conduit system, as exemplified chiefly by the London County Council tramways in this country, the rails are not used as part of the electrical circuit, but positive and negative conductors are fixed in the conduit, both insulated from earth. As in other tramway systems, these conductors are sectionalised every half mile, but in this case the sections are permanently separate. Every half mile section has a separate positive and negative feeder from the generating station or sub-station, and the conductor rails are utilised only for the distribution of current on their own half mile.

Provision is made at the station end of the feeders for reversing the polarity of any pair of conductor rails, so that if there should at any time be two earths in the system they can both be transferred to the positive or negative pole as desired.

Auxiliary feeder system. In the auxiliary system may be included those conductors which do not serve for the transmission of energy, but are required for some subsidiary purpose. These purposes are chiefly the testing of the drop in the earthed return at the far ends of the line, and the provision of telephone circuits whereby communication is effected between outlying parts and the generating station.

The test wires are required for demonstrating that the Board of Trade requirements are being complied with, and as a general rule one test wire must be laid to each extremity of the system. If the system consists chiefly of lines which radiate out from the centre, the test wires must be connected to the rails at the farthest point; if the lines at the far end are connected by loops the connections must be made at the farthest points of such loops. It is true that these points do not in all cases necessarily represent the position of maximum rail drop, but as a general rule this will hold good.

* See *Tramway and Railway World*, Aug. 1900, or *Street Railway Journal*, June 1901.

In almost all systems provision is made for a telephone connection either at or close to each section pillar. Where the energy is distributed without transformation from a single low tension generating station the requirements are met by a system in which each section pillar can call up the generating station, there being no necessity for the reverse process. A pair of wires for each route is all that is necessary for any number of telephones, it being entirely a matter of convenience how many instruments should be put on each pair of wires. It frequently happens that at or near the far end of a route a car shed or depôt is situated which the generating station may wish to call up. This can be effected with the same two wires by means of a polarised bell*. In large systems a more extensive installation of telephones may be required; the following is an account of the system provided specially for the Glasgow Corporation tramways†:

"(1) A 100-line switchboard at head office, with lines to the Pinkston power station, 5 sub-stations, 14 depôts, and all the official residences of the staff, numbering about 35 stations.... There are about 40 telephone street posts....

"(2) A 12-line switchboard at Pinkston power station, of similar type to that at the head office, with lines to the 5 sub-stations and chief official residences....

"(3) Every section pillar, of which there are 142, is fitted with a G.E.C. patent 'traction' telephone plug box, and these all radiate to the nearest sub-station, where they call up the special terminal telephone...."

General information about electric cables for tramways. In general it may be said that only two types of cables are available for electric tramways, viz. cables drawn into earthenware ducts, and cables laid solid. Armoured cables buried in the ground are very seldom used, chiefly because of the liability to corrosion of the armouring and lead sheath.

Of the two available systems, that in which the cables are laid solid is in more general use, being as a rule cheaper than the drawn-in system; but in very large and extensive tramways the balance of economy is in favour of the latter. In such cases an additional advantage is secured, in that spare ways can be put down, so that extra cables can be drawn in subsequently without requiring any fresh disturbance of the ground.

The solid system. This consists in laying in a trench in the ground a trough of suitable material, in which a lead-covered cable is

* See General Electric Company's Catalogue of Telephones.

† *Electrician*, September 13, 1901, p. 811.

inserted and completely surrounded with a trough-filling compound. After the cable is laid in, and the trough filled up, a cover is put on and the trench filled in.

There are several kinds of trough manufactured, viz.:

Wood trough with hard tile cover,
Earthenware trough with hard tile cover,
Earthenware trough with earthenware cover,
and Cast iron trough with cast iron cover.

The standard length of the earthenware trough is two feet, and successive lengths are fitted together with a spigot and socket joint; troughs of wood or cast iron may be of any suitable length, such as 12 or 20 feet. Wood troughing is jointed by fitting the bottom of one trough into the facing one, as in figure 151. Such long troughs are better than the short earthenware ones in places where there is a possibility of subsidence.

FIG. 151. Method of jointing wooden troughing.

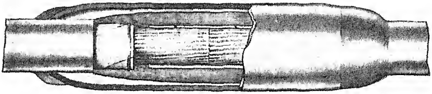


FIG. 152. Construction of lead sleeve joint for lead-cased cables. (Siemens.)

The size of a trough is always such as to allow at least $\frac{1}{2}$ in. clearance all round the cable. This space is filled with compound, and it is easy to calculate the amount of compound required for any size of cable, allowing 65 lbs. weight per cubic foot.

Drawn-in cables. In the alternative system, lead-cased cables are drawn into earthenware ducts, buried in the ground. The conduits are generally set in concrete, which provides a firm watertight support. For the purpose of drawing in, brick chambers are constructed about every 100 yards, the exact distances apart being made to suit the local circumstances and the manufactured lengths. Thus for instance a 1 sq. inch cable, of which the length per drum is 255 yards, would require chambers spaced about 85 yards apart, so that the joints may be situated in accessible places.

On both systems the joints are now generally made with lead sleeves. Figure 152 shews the construction of the joint as made in

a ·5 sq. inch lead-cased cable. The lead sleeve is first threaded on to one cable end, from which the lead and the insulation have been stripped for a suitable length. A joint is then made between the abutting conductors in the usual way, and when it is completed the sleeve is slid over and fixed in place by a wiped joint at each end. Finally the interior is filled with insulating compound through a small hole in the sleeve, and the hole then soldered up. This method of jointing eliminates the necessity for joint boxes.

TABLE 19. *Single low tension lead-cased cables.*

Nominal area* sq. in.	Ohms per 1000 yds.†	Over-all diam. inches	Nett weight per 1000 yds. cwts.	Length per drum yds.	Shipping specification per drum: Gross wt. cwts.	Shipping specification per drum: Dimensions	Weight of compound per 1000 yds. cwts.
·025	·9810	·484	14·2	2000	31	49″ × 49″ × 25″	24·3
·05	·5027	·565	19·1	2000	41	,,	26·6
·075	·3230	·660	26·9	1860	53	51″ × 51″ × 28″	29
·1	·2490	·730	31·8	1570	,,	,,	31
·125	·1978	·780	36·1	1385	,,	55″ × 55″ × 29″	32·4
·15	·1660	·845	43·8	1140	,,	,,	34·4
·2	·1280	·914	50·8	985	,,	,,	36·4
·25	·1016	1·024	64·0	780	,,	,,	39·6
·3	·0843	1·087	72·0	695	53½	57″ × 57″ × 32″	41·4
·35	·0711	1·150	80·5	620	,,	,,	43·3
·4	·0618	1·226	93·6	535	,,	,,	45·6
·5	·0512	1·309	106·2	470	,,	,,	48·1
·6	·0431	1·430	126·6	395	54	60″ × 60″ × 35″	52·1
·7	·0364	1·518	142·5	350	,,	,,	54·5
·75	·0343	1·551	148·7	335	,,	,,	55·6
·8	·0323	1·624	163·1	305	55	62″ × 62″ × 39″	58·1
·9	·0289	1·690	176·5	285	,,	,,	60·5
1·0	·0251	1·798	196·7	255	,,	,,	64·1

Conduits for drawn-in cables are very often laid in the concrete on which the track is laid. Repairs to such cables must, then, be done at night time; but it is quite possible to draw out three-quarters of a mile of cable and draw in a fresh one in a single night.

Cables laid on the solid system are generally put at the side of the road or under the footpath. It is best not to lay them too close to the

* The nominal area of a cable is approximately the effective area, the approximation being due to the employment of standard sized wires.

† The resistance per 1000 yds. is the maximum allowable resistance for each cable in accordance with the tables drawn up by the Engineering Standards Committee.

track on account of possible corrosion (for the compound generally used is not a particularly good insulator).

Connections to feeder pillars can be made in two ways, depending upon the space available: (1) the cable can be broken at the feeder pillar and the two ends brought up to suitable terminals, or (2) a tee joint can be made and the tee piece, which is generally of rubber-covered cable, brought into the feeder pillar. If the two ends of the feeder be taken into the pillar provision must be made for sealing the end and insulating it. This can be effected by means of a porcelain sleeve, within which a terminal can be jointed to the cable end, and the joint properly insulated with compound.

Connections from the feeder and section pillars to the overhead line are made with rubber-covered cable, sometimes lead-cased.

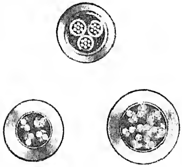


FIG. 153. Sections of three auxiliary cables, viz. a 3-core test, a 4-pair telephone, and an 8-pair telephone cable. (Siemens.)

Auxiliary cables. Telephone and test cables are made up and laid in the same way as power cables. Figure 153 shews three such cables, viz. a 3-core test, a 4-pair and an 8-pair telephone. It is the general practice now to make up separate cables for auxiliary purposes, and to lay them in separate troughs. Formerly, power cables used to contain a small core for a voltmeter lead, but this method has been abandoned.

Reinstatement. A special word of caution is necessary in connection with the preparation of preliminary estimates for feeder systems. The cost of cables may be worked out, including laying and jointing; and in general the estimation of the labour involved in trenching presents no difficulties, except in the case of crowded thoroughfares, where it is often very costly to get past buried obstacles such as water and gas mains. But the cost of reinstatement of the surface varies between very wide limits. If the surface is macadam the cost is far less than if it is some special type of paving. It is therefore necessary to proceed with caution in this matter.

CHAPTER 10.

GENERATING STATIONS FOR DIRECT CURRENT TRAMWAYS.

General. The design of generating stations is a subject which cannot be adequately treated in a book devoted to Electric Traction, and it is proposed to discuss here only those features which are peculiar to tramway stations.

All generating stations are built for the same purpose, namely, that of supplying electrical energy to consumers. Considerable differences arise, however, according to the nature of the consumer, that is to say, according to the character of the load. A lighting load differs entirely from that on a tramway. The principal characteristic of the output from a traction generating station is its extreme irregularity. On small systems the line current may vary in the space of a few seconds from zero to two or three times the average value. The first and chief question, therefore, which arises in this connection is the capacity of the plant required.

Capacity of plant. The chief consideration on which the decision is based as to the capacity of the generators, is naturally the number of cars that will be in use at the same time. This number usually varies throughout the day and is generally greater in the morning and evening. Knowing the details of the service and the equipments of the various cars, a fairly accurate estimate can be formed of the average demand in the busiest times of the day (see chapter 9). This estimate, however, in itself is not sufficient to settle the question. The maximum demand differs from the average more and more widely the smaller the system, and it is obvious that the maximum demand must be satisfied. The three curves in figure 154 shew how this relation varies with the magnitude of the system. These curves are from actual tests, curves A and C being respectively for 6 and 66 cars on the Leeds Tramways*, and the curve B for 22 cars being taken from Mr Highfield's paper on reversible boosters in traction stations†.

* See Electric Tramways by Hopkinson and Talbot, *Proc. Inst. C. E.*, vol. 151.
† *Proc. Inst. E. E.* for May 9, 1901.

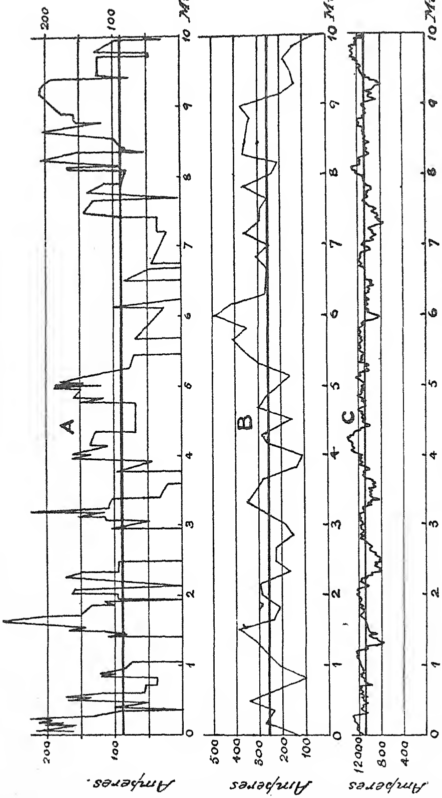


FIG. 154. Curves shewing variation of generating station output in the cases of 6, 22 and 66 cars respectively.

From these curves it will be seen that for 6 cars the maximum is approximately three times the average, and that on one occasion in the 10 minutes there is a fairly steady demand for about half a minute of twice the average value. For such a system, therefore, it is evident that the engines and generators must be designed to give an output of at least twice the average demand, and that the generator itself must be capable of withstanding momentary overdrafts of current up to three times the average. How far this peak load should be dealt with by means of the flywheel is a question which is discussed below.

From the second curve B it will be seen that the maximum current is nearly twice the average and that in one case there is a fairly steady demand for half a minute about 50 per cent. greater than the average.

The third curve C, viz. for 66 cars, shews that the variations about the mean value are much smaller than in the previous cases, the maximum being about 20 per cent. greater than the mean.

These three curves give a very fair idea as to what demand should be provided for as far as the generators are concerned. It is usual to specify for traction generators that the machines should be capable of giving 25 per cent. overload for 1 or 2 hours, and 50 per cent. for short periods, without any injurious results and without any change of the position of the brushes. Taking these overload figures it will be apparent that for the 6 cars the generator capacity on the basis of the normal rating should be, apart from spares, 100 kw., for the 22 cars, 175 kw., and for the 66 cars, 600 kw.

Capacity of engine and size of flywheel. The flywheel of a steam generating set has two functions to perform. In the first place, by virtue of its rotation it possesses a large store of potential energy and therefore acts as a reservoir, giving out energy at momentary overloads and receiving it when the demand is below the normal. In the second place it acts as a damper against excessive speed variation. Short circuits are very frequent occurrences in tramway stations and result in the opening of the circuit breakers and the consequent removal of all load from the generators. On such occasions it is of the greatest importance that the engines should not race. A very usual specification requires that the variation of speed when full load is suddenly thrown off shall not exceed 5 per cent. momentarily and 2 per cent. permanently. Now it is impossible for the governor to come into operation instantaneously, and consequently a flywheel is necessary to limit the rate at which the speed rises before the governor comes into action.

The flywheel effect of the rotating parts is reckoned in foot tons at the normal speed. Thus, suppose the total mass of the rotating parts

is 25 tons at an effective radius of 8 feet, the speed of the set being 90 revolutions per minute. Then the flywheel effect will be

$$\frac{w \cdot v^2}{2g} = \frac{25}{2 \times 32{\cdot}2} \times \left(2\pi \times 8 \times \frac{90}{60}\right)^2 = 2200 \text{ foot tons.}$$

This may conveniently be converted into kilowatt seconds by multiplying by $\frac{2240}{550} \times {\cdot}746$ or 3·04, so that the rotating mass in the above example would have a stored energy of 6700 kilowatt seconds.

To continue the illustration, let it be supposed that the above flywheel effect is associated with a 750 kw. steam engine and generator. If the load on the generator be 750 kw., and at a given moment the circuit be opened suddenly, an accelerating force is suddenly set free which is equivalent to 750 kw. at the speed of working. This force, acting on the rotating mass, which at that speed has 6700 kilowatt seconds stored energy, would increase the stored energy by 10 per cent. in about $\frac{670}{750} = {\cdot}9$ second; and since the stored energy is proportional to the square of the speed, the acceleration would be such that in ·9 second there would be an increase of speed of practically 5 per cent., on the assumption that the force exerted by the engine remains constant during this period.

Now in ·9 second the set would perform 1·35 revolutions, and with some types of engine there would be enough steam in the cylinders and steam passages to maintain the accelerating force approximately constant. This matter differs for different engines, but the above will serve well enough as an illustration of actual practice.

The question may, therefore, be considered how far the flywheel may be used for getting over the momentary peaks in the load. It is evident from the above that, allowing for a 5 per cent. drop in speed, the energy given out by the flywheel would be 10 per cent. of 6700 kw. seconds or 670 kw. seconds. If, therefore, a momentary overload of 50 per cent. comes on, the flywheel will be capable of supplying the necessary energy for $\frac{670}{{\cdot}5 \times 750} = 1{\cdot}8$ seconds with a 5 per cent. drop of speed. If the overload lasts longer than this the engine must be capable of supplying the necessary power.

As a practical conclusion, then, it may be taken for granted that the flywheel effect of a traction set is only good for very brief overloads, and the electrical engineer need not concern himself in the matter beyond specifying to the engine builder what momentary and permanent variations in speed he requires, when full load is thrown off and on.

For the three cases already cited, it is, therefore, sufficient to specify the mean load on the engine and the overloads, and it is evidently unnecessary to take into account the small reductions due to

the flywheel capacity. The following can then be made out for these cases, by taking into account the generator efficiencies:

	Cars		
	6	22	66
Average output, kw.	50	132	600
Maximum output, kw.	150	264	720
Generator full load capacity, kw.	100	175	600
Generator momentary overload, kw.	150	264	
Normal B.H.P. of engine $\left(= \frac{\text{average output}}{\text{efficiency}} \text{ expressed in B.H.P.}\right)$	75	about 200	880
Maximum B.H.P. of engine $\left(= \frac{\text{maximum output}}{\text{efficiency}} \text{ expressed in B.H.P.}\right)$	220	385	1050

Spare plant. The above table is intended to express not necessarily the capacity of the generating station nor the capacity of a single set, but simply the working capacity that has to be provided.

The question of spare plant is a matter which belongs to the subject of power house design, but it may be said briefly, here, that it is wise to make provision for a margin of from 50 per cent. to 25 per cent. Thus, for instance, in the first case it would be advisable to provide two generators of 100 kw. capacity each; in the second case, two generators of 175 kw. each; and in the third case probably three generators each of 300 kw. capacity.

This, however, is a matter which must be examined in conjunction with the rest of the plant, chiefly the storage battery. Further, account must be taken of the duration of the average load; thus, for instance in the third case the demand for 600 kw. may not last more than one hour in the morning and one in the evening. In such a case this load might be regarded as the one hour overload of the generators, or the battery might be employed to keep down the demand on the generating plant. In any case, the capacity of the station must be considered as a whole, including generators and battery*.

Buffer batteries. From what has been said as to the relation between the average output and the capacity of the generating plant, it will be obvious that in those cases in which there are only a few cars to be supplied, the generating sets are constantly working much below their limits. This affects matters in two ways, viz. (1) the sets are much larger than the requirements of the average load would dictate, and are therefore more expensive and (2) they are in general working considerably below their most economical loads.

* For the design of the generating station in general, reference should be made to such a book as *Central Stations*, by Wordingham.

This matter has attracted the attention of engineers, and in May, 1901, Mr J. S. Highfield read a paper before the Institution of Electrical Engineers in which he advocated the use under such circumstances of a storage battery in combination with an automatic reversible booster. The purpose of the battery is to act as a reservoir of energy, from which current may be taken at moments of heavy load to assist the generators, and to which current can be supplied from the generators at times of light load. If this could be realised, the effect would be to reduce the capacity of the generating plant, under ideal conditions, to such an extent that it only has to meet the average demand from the line together with the losses inherent in the operation of the battery and the automatic apparatus.

To carry into effect this purpose he invented an automatic reversible booster, the function of which is to raise the effective voltage of the battery at times of heavy load so that it may be discharged, and to lower the voltage at times of light load below the generator voltage so that it may receive a charge.

Consider, now, the effect of such an auxiliary battery working in this way. In the case mentioned above, in which there were 22 cars, it was estimated that the steam engine would be required to give out, at times, 385 B.H.P., whereas its mean load was only 200 B.H.P. As an example, suppose the engine to be a two crank compound working at 380 revolutions per minute, with 160 lbs. per square inch pressure, and 27 inches vacuum. On full load such an engine might be expected to have a steam consumption of 19 lbs. per B.H.P. hour and on half load 23 lbs. per B.H.P. hour, or about 26·3 lbs. per kw.h. on full load and 33·5 per kw.h. on half load. With no auxiliary battery the latter figure must be taken.

On the other hand, when a battery is used a careful examination of the curve B in figure 154 will shew that the area above the mean line amounts to about 10 per cent. of the total area, or in other words the battery and booster would be required to supply about 10 per cent. of the total output. Taking an over-all efficiency of 80 per cent. for the battery and say 60 per cent. for the booster, the losses to be supplied by the generator would be about 35 per cent. of the 10 per cent., that is 3·5 per cent. of the output. The following comparison can then be made:

	Without battery	With battery
Average output	132 kw.	132 kw.
Average load on generator	132 kw.	136·5 kw.
Steam consumption per kw.h.	33 lbs.	say 28 lbs.
Average steam consumption per hour	4350 lbs.	3820 lbs.

Thus the addition of the battery effects a saving of about 12 per cent. in the steam consumption. This comparison is based on the

curve in figure 154, and gives results somewhat more favourable than are attained in practice. Mr Highfield quotes, in his paper, the result of observations continued during one month, and finds that 94 per cent. of the energy generated was delivered to the line. It is obvious that the final result is very slightly affected by this difference.

Relative cost of battery and generating plant. In comparing the two systems, viz. that in which the generating sets are made capable of dealing with the maximum load, and that in which the peak loads are taken by a buffer battery, it is necessary to consider first cost. For tramway stations the comparison may be confined to the relative cost of battery and accessories and of generating sets, since the boiler capacity is practically unaffected.

As an example, take the case already quoted, viz. that in which 22 cars are supplied. The cost of the generating sets may be estimated roughly on the basis of 30*s.* per kw. normal rating for the generator and 50*s.* per B.H.P. maximum output of the engine. (These are approximate figures only for high speed reciprocating engines.) The cost of a battery to give about 200 amperes for one hour, or say 250 amperes maximum, consisting of 240 cells (the number recommended by Mr Highfield) would be about £1200, including automatic booster and switch gear.

The comparison would therefore be as follows:

	Without battery	With battery
Two 175 kw. generators	£524	
Two 380 H.P. engines	£1900	
Two 132 kw. generators		£396
Two 220 H.P. engines*		£1100
Battery and accessories		£1200
Total	£2424	£2696

The difference in cost is therefore £272. The final balance sheet should be made on the basis of the combination of working expenses with charges for interest and depreciation. Allowing for coal at 15*s.* per ton, and assuming 10 lbs. of steam produced per lb. of coal and 5000 effective working hours per annum the saving in cost of coal works out at $\frac{1}{2240} \times \frac{560}{10} \times 5000 \times \frac{15}{20} =$ **£94 per annum.**

To complete the comparison, the following figures may be taken; interest on capital 4 per cent., maintenance and depreciation of battery 6 per cent., maintenance and depreciation of generating sets 6 per cent.; that is to say, 10 per cent. on the outlay in both cases for interest, maintenance and depreciation.

Operating cost	Without battery	With battery
Economy in fuel consumption		£94
Interest, maintenance and depreciation	£242	£270
Nett economy in favour of battery		£66

* Allowing 10 per cent. variation above the mean.

General consideration. The above figures must not be looked upon as anything more definite than a demonstration that a certain amount of saving may be expected, although not a great deal. Many engineers, however, are of opinion that no generating station should be without a battery, for many reasons. If then a battery is installed, it is fairly obvious that there is an advantage in the introduction of an automatic booster, provided the load is sufficiently peaky. It is equally obvious that when the variation of load is not worse than that shewn in figure 154 for 66 cars, an automatic booster is an unnecessary complication.

The automatic reversible booster. The apparatus whereby the battery is automatically charged and discharged as the load varies is primarily due to Mr Highfield, who described his invention in the communication to the Institution of Electrical Engineers already referred to. Various modifications have been brought out since, notably by the Lancashire Dynamo and Motor Company, but also by others.

The essence of the Highfield booster is the provision of a voltage which does not depend upon the bus-bar voltage or upon the load on the station. This voltage is approximately equal to the mean bus-bar voltage and supplies a standard basis to which the latter can be compared.

The booster consists of three machines, the motor, the booster proper B, and the exciter E, all three being rigidly coupled together. The motor drives the set taking power from the bus-bars, and is designed to maintain a constant speed as nearly as possible under all circumstances. The booster B is a machine of the ordinary direct current type, the armature of which is connected in series with the battery while the field coil C is excited by a current due to the difference of voltage between the exciter E and the bus-bars. The exciter is simply a small direct current shunt wound self-exciting generator. The booster is designed with such proportions that at the given speed the voltage generated in the armature is exactly equal to the volts at the terminals of its field coils. Its field is also provided with a small series winding for counteracting the drop in the armature and series turns.

A diagram of connections is shewn in figure 155, from which and from the above description it will be seen that if an increase of the external load takes place, and the generator volts tend thereby to fall below the mean value, a difference is set up between the E.M.F. of the exciter E and the bus-bar voltage. This difference being applied to the excitation of the booster B, produces an E.M.F. in the booster armature which assists the battery E.M.F., and therefore causes the battery to discharge. Thus a small change in the generator current will produce a considerable change in the battery current, and in this way the load on the

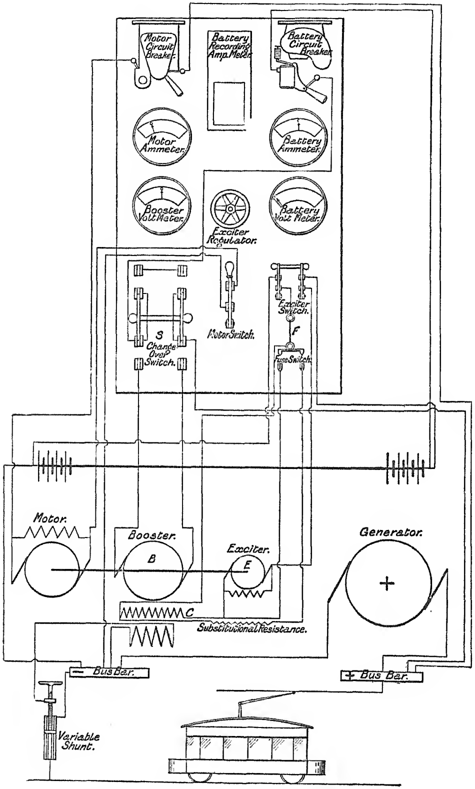


FIG. 155. Diagram of connections for Highfield's automatic reversible booster.

generator is equalised, the peaks above and below the mean of the external load being assigned to the care of the battery.

*The Lancashire Dynamo and Motor Company booster set consists of only two machines, motor and booster. The booster proper is supplied with 4 excitation coils, A, B, C and D; see figure 156.

A is a shunt winding across the booster terminals to which is applied the difference between the battery and the bus-bar voltages.

B is a shunt winding excited by the bus-bar voltage through a potentiometer regulator.

C is a series coil connected between the negative terminal of the main generator and the negative feeder to the external circuit.

D is a series coil in series with the booster armature whose function is to compensate for armature reaction and internal drop.

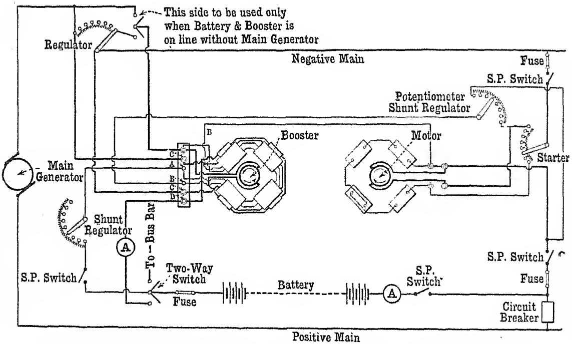


FIG. 156. Diagram of connections for the Lancashire Dynamo and Motor Co.'s automatic reversible booster.

The operation is as follows: Neglecting coil D as a mere compensation, the windings B and C are designed to counteract each other exactly when the current from the main generator is at the predetermined value. B and C thus neutralising each other, the excitation is due to A alone; *i.e.* when the generator current is at the correct value the booster volts must be exactly equal to the difference between

* See *Electrician*, June 10, 1904, page 303.

the battery and the bus-bar voltages. If the current in C rises a little, the coil C overpowers the coil B and produces a discharge from the battery, whereby the extra demand is almost entirely diverted from the main generator.

The **Entz booster** is shewn diagrammatically in figure 157 and employs, as its chief feature, a carbon regulator placed as a shunt across the battery. Between the mid-points of the carbon piles and the battery respectively is placed the excitation coil of an exciter which in turn supplies the excitation current for the booster. The booster and exciter are driven by an electric motor or other prime mover. The load current is passed through a solenoid whose core is

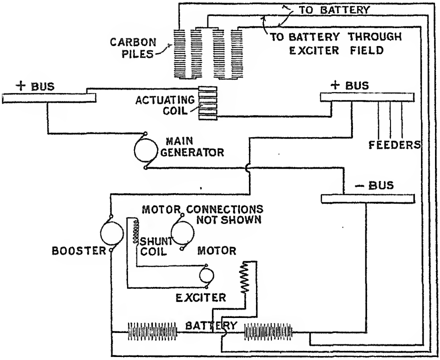


FIG. 157. Diagram of connections for Entz reversible booster.

attached to a lever shewn in figure 158. The lever on the side of its fulcrum remote from the solenoid core is so attached to the carbon piles that as the pull due to the solenoid varies, the resistances of the respective halves of the carbon resistance are also varied—the one half being increased when the other is decreased. The result is that for a certain value of the pull of the solenoid the current in the exciter field coil is zero. An increase or decrease in the pull causes a positive or negative current to flow through the exciter field coil. In this manner the booster is excited positively or negatively to a degree depending upon the pull, that is to the strength of the current in the main circuit. The lever is attached at its extremity to a dash pot to steady its motion.

It will have been noticed in connection with other boosters that the field of the booster itself is excited by a shunt coil and a thick wire coil which carries the main current or a certain proportion thereof. The Entz booster has the advantage that it is wound with the single shunt only. The "diverter" is dispensed with. This booster is in operation in the Greenock Corporation tramway system, and is giving excellent results.

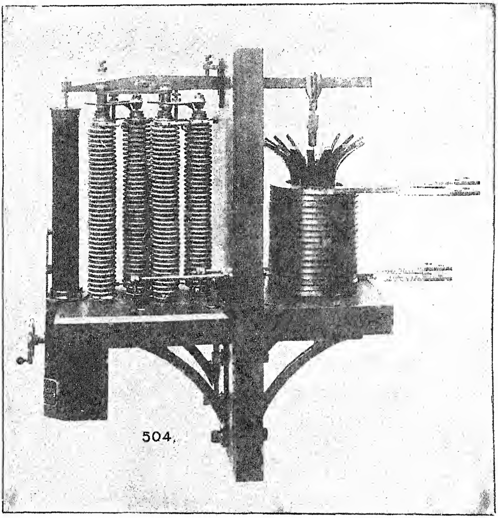


FIG. 158. Carbon regulator for use with Entz reversible booster.

There are several other types of automatic booster, such as that of the British Westinghouse Company, in which the exciter has a differential field winding partly shunt and partly series, and Messrs Crompton's which is somewhat similar to that of the Lancashire Dynamo and Motor Company's system, and also that invented by M. Thury, which consists in the use of a small motor working a rheostat connected in the exciting circuit of the booster. Those described above are, however, most frequently met with.

Voltage and type of generators. In the early days of electric traction it was customary to use over-compounded generators giving 500 volts on open circuit and 550 volts on full load, and this is still specified in many cases. It has been pointed out, however, that for rapidly varying loads the compound winding of the generators cannot produce a corresponding variation of the field strength because of the eddy currents set up in the magnet cores and the yoke. Prof. B. Hopkinson has suggested, therefore, that machines should be level compounded for 550 volts, and at times of very light load the voltage can be adjusted by hand to 500, if it is considered worth while.

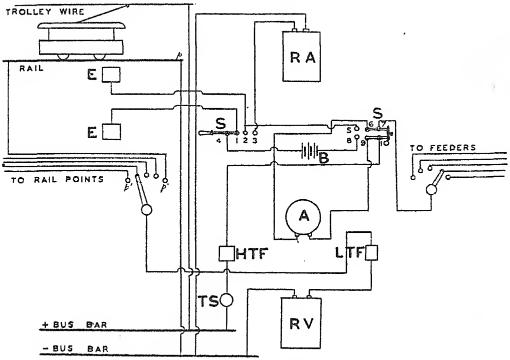


FIG. 159. Diagram of connections for the Board of Trade panel. Generating station close to track.

For traction stations where buffer batteries and Highfield automatic reversible boosters are used, it is advisable to employ shunt wound generators which drop their voltage slightly as the load increases. It is, however, to be recommended that such a machine should be provided with a series winding for converting the dynamo into a compound generator at such times as the battery for any reason is not working.

Switchboard. Very little need be said about the switchboard for a traction station, as it only differs from that in other stations in a few respects. One of the chief differences is the necessity for providing a Board of Trade panel, on which are mounted the instruments and switches for indicating the various measurements required by the Board of Trade.

The Board of Trade panel is located in the generating station, which may or may not be close to the track. Figure 159 is a diagram of the connections when it is close to the track, and figure 160 is a diagram when the track is about 200 yards or more away. Referring to figure 159, EE are the earth-plates mentioned in the Board of Trade protective regulations (see Appendix, page 443), and RA is the recording ampere-meter mentioned in Reg. 5 (*a*). It will be seen that it records any current which returns to the negative pole of the generator via the earth-plates EE when the switch S is so placed as to connect the studs 1, 2 and 3. In order to make sure that the earth-plates are making

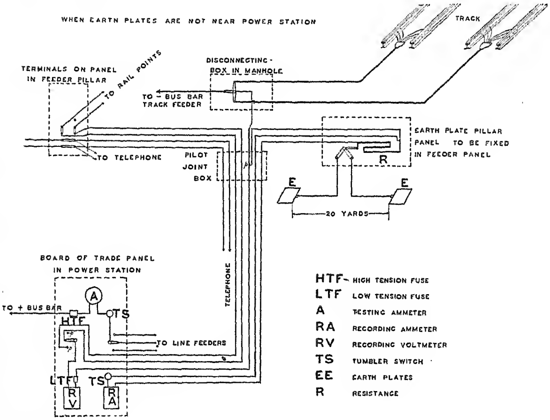


FIG. 160. Diagram of connections for the Board of Trade panel. Generating station distant from track.

proper contact with the earth a test can be made by throwing over the switch S to connect studs 1 and 4, the switch S′ being so placed that the studs 5, 6 and 8, 9 are respectively connected together. The ampere-meter A should then indicate the current caused by the battery B, which must be at least 2 amperes when the potential difference of the battery is not more than 4 volts. It is important that the internal resistance of the cells should be so small or that their number should be so great that when delivering this current they may have the requisite terminal volts as mentioned. Storage cells are suitable.

When the nearest point on the track is a considerable distance away from the generating station, there may be a substantial fall of potential in the feeder which connects the track with the negative pole of the generator. If the earth-plates were located near the generating station such a potential difference might cause a considerable current to traverse them. Hence their location near the track. Under these circumstances it would lead to unnecessary expense to connect up these two earth-plates by separate cables to the recording ampere-meter RA located in the generating station; as, unless the resistance of the cables was very small, the track would not be sufficiently well earthed at this point. It would be inconvenient to have a recording ampere-meter located near the track at such a distance from the station.

To get over this difficulty a shunt R (figure 160) is allowed, its resistance being such that it shall not have a potential difference more than 1 volt between its ends when traversed by the maximum current which is allowed and which must not exceed 2 amperes per mile of single track, or 5 per cent. of the total current output of the station. The recording ampere-meter RA (figure 160) can then be located in the station and connected to the shunt R by insulated pilot wires as shewn. The Board of Trade now allow of a low resistance maximum demand ampere-indicator of good design being used instead of the shunt R. This dispenses with the recording ampere-meter RA.

The recording voltmeter RV (figures 159 and 160) is connected at one terminal to a point p, which is a point virtually in the part of the track nearest to the station, and at the other terminal to points $p'p'$, which are connected by suitable pilot wires to the points in the track between which and the point p the potential difference is to be recorded and is not to exceed 7 volts (Reg. 7, page 445).

The leakage over the overhead line insulators and its feeders has to be measured and must not exceed $\frac{1}{100}$th ampere per mile (Reg. 11). To carry out this test the ampere-meter A is employed when the line is fully charged and when no current is otherwise being taken, by throwing over the switch S′ (figure 159) so as to connect 6, 7 and 9, 10 respectively. This test causes inconvenience when power is required in car sheds at times when the outside service is suspended, and has given rise to Reg. IX, page 450. The test of the line insulators under this Regulation is further dealt with at page 147. In figure 160 no provision is made for measuring the resistance between the plates EE and the earth by aid of the ampere-meter A. As shown in figure 160, this instrument is only used for line leakage tests.

Choice of site for power house. The question as to the best situation for a power house for an electric tramway system can only be

answered in general terms. As a rule there is very little choice of favourable sites, and it can only be said that other things being equal it is better to put the power house as near the centre of the system as possible. But such a statement is, naturally, of very limited application, for other things will very seldom be equal; in particular, when the centre of the system coincides with the centre of a town, as is often the case, the cost of land is much greater there than in the outlying parts. In every case, therefore, the engineer must use his own judgment, bearing in mind not only the cost of the land and the cost of the feeding system, but also the accessibility of the station for the supply of coal, water and machinery.

Various rules have been given by different writers for finding the centre of the system, resembling methods for finding the centre of gravity of a number of equal bodies. The analogy, however, is not sufficiently close for the rules to be of much value; and it is probable that in most cases one could estimate the centre at sight with sufficient accuracy for all practical purposes.

CHAPTER 11.

CAR SHEDS AND REPAIR SHOPS.

The housing of cars is an important item in the equipment of a tramway system, as it is necessary to clean and overhaul them regularly, and a certain amount of repair work must be provided for. The sheds should be laid out so that the various operations can be performed with the utmost economy. In addition to the storing of material it is necessary to provide a certain amount of office accommodation. Recreation rooms are also provided.

Space does not allow of an exhaustive treatment of this subject. The Bexley Urban District Tramway Depôt is dealt with in some detail and is an instance of a small undertaking*. The plan of the car depôt is given in figure 161, and provides accommodation for 18 cars. The actual number of cars is at present 16, of which 7 are in regular operation, and more are required at the week-ends. The Leicester Corporation Tramways Depôts are briefly described, and as there are about 60 cars on this system it may be taken as a typical example intermediate between the above and the very large tramway undertakings. The large systems are briefly alluded to, and a plan of the car shed at Coventry Road, Birmingham, is given in figure 162 as a good example of a large shed†.

The buildings. The size and number of sheds naturally depend upon the size of the system, and in the case of large undertakings more than one shed is required. The number of tracks and their length for a given accommodation depend upon the length and breadth of the available site. It may be said, however, that in case of fire a number of tracks is an advantage. In nearly all cases the cars leave the sheds by the same doorway through which they enter, and this involves turning round the trolley. At West Ham the cars run through the shed. As regards superficial area one may say that for ordinary single-truck

* The authors are indebted to Mr C. Mittelhausen for the information relating to his system at Bexley.

† The authors wish to thank Mr Stilgoe, the City Engineer and Surveyor of Birmingham, for this plan.

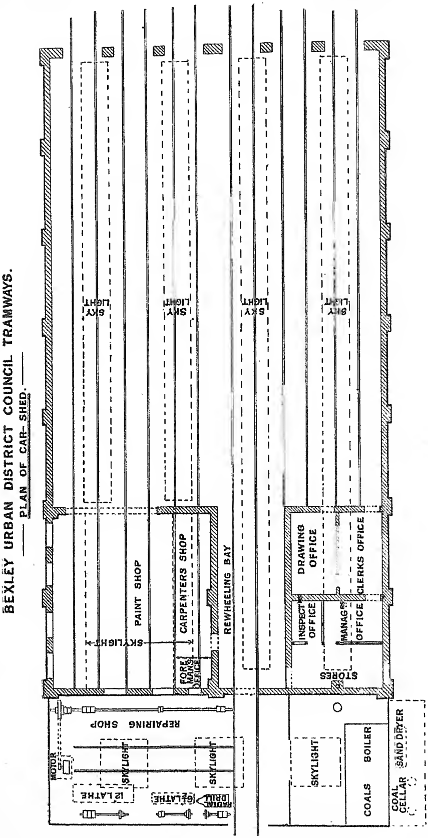

BEXLEY URBAN DISTRICT COUNCIL TRAMWAYS.
PLAN OF CAR-SHED.
SKY LIGHT
SKY LIGHT
SKY LIGHT
SKY LIGHT
PAINT SHOP
CARPENTERS SHOP
SKYLIGHT
FORE MANS OFFICE
REWHEELING BAY
DRAWING OFFICE
CLERKS OFFICE
INSPECTS OFFICE
MANAGRS OFFICE
STORES
REPAIRING SHOP
MOTOR
SKYLIGHT
SKYLIGHT
12 LATHE
6 LATHE
RADIAL DRILL
SKYLIGHT
BOILER
COALS
SAND DRYER
COAL CELLAR

Fig. 161.

cars a length of about 32 ft. of track is desirable. When the gauge is 4 ft. $8\frac{1}{2}$ in. and the width of the interspaces is 6 ft. an area of about 340 sq. ft. per car is required. This area may be increased on the average to 360 sq. ft. when allowance is made for bays, &c. For bogie cars a proportionately greater length must be allowed, the width remaining the same. The walls are generally of brick and about 20 ft. high unless an overhead traveller is required, which is only the case in large repair shops. The shutter type of door, or "rolling blind," is usually employed at entrances, and as it is rolled up from above it is necessary to make provision for breaking the overhead conductor. This is accomplished by allowing the ends of the conductor, between which the shutter passes, to terminate in an insulation piece about a foot long. A short metal runner is fixed to the bottom of the shutter to bridge across the gap, and the car has to coast over the joint. Wooden doors which open on either side of an entrance have the advantage that the trolley wire need not be broken, but they are said to warp. The overhead conductor in the shed is supported by an insulated ear of the ordinary type, but the casting which supports the ear is screwed to an inverted wooden trough running the length of the pit and fixed to the roof. Means should be supplied for cutting off current from the overhead conductor in sheds if required.

Artificial lighting above the track level is sometimes carried out by arc lamps, but incandescent lamps are also used. The shed proper in figure 161 is lighted above tracks by seven rows, each having three 16 C.P. lamps. The car lights are also available.

The track inside the shed is best made of flat-bottomed rails, as there is a liability with grooved rails to get spanners, etc., trapped by the car wheels. About 80 lbs. per yard is a good section. A large number of sheds however have the ordinary girder rail. The tracks are sometimes supported on brick piers the height of which varies, but 4 ft. 6 ins. is a common distance between the track level and the bottom of the pit. The best construction is to support the rails on cast iron columns, a common size having external and internal diameters of 6 ins. and $4\frac{1}{2}$ ins. respectively. The columns are let into the concrete foundations to a depth of about 2 ft. and terminate at the bottom in a 12 in. square flange. The upper end is also supplied with a flange to which the rails are bolted. Just underneath this flange a lug is cast, so that two L steels 3 ins. × 3 ins. × $\frac{3}{8}$ in. can be bolted thereto, to bridge across the interspace for the support of the floor boarding. For a 4 ft. $8\frac{1}{2}$ in. gauge the distance between centres transverse to the track length is 4 ft. $9\frac{1}{2}$ ins. for pit, and about 6 ft. for the interspace. Longitudinally the columns can be spaced out at about 9 ft. centres, but regard must be paid to the length of the track rails, as each joint must be arranged

to come over a column. A usual length for the rails is 45 ft. The floor at the bottom of the pits should be suitably sloped for drainage. The lay-out of the entrance track depends upon the relative directions of the tracks in the sheds and the entrance line to the depôt. In connection with figure 161 the entrance line is in the same direction as the car shed tracks, but more usually the entrance line is at right angles to the shed tracks as shewn in figure 163. This arrangement economises space and involves less complication. In order to equalise the wear on the wheels it is good practice to turn round each car periodically on the track for a given direction. The entrance track can be arranged so that this is automatically done each time a car enters and leaves the depôt. The arrangement is shewn for a single track system in figure 162, the car entering by one curve and leaving by the other.

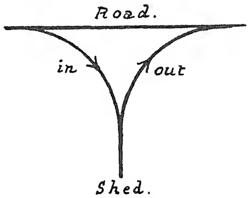


FIG. 162. Diagram of track at the entrance to a car shed for reversing cars.

Traversers are sometimes employed on large systems for transporting cars from one track to another. They are valuable in conduit systems where points are expensive. The traverser runs at right angles to the shed tracks on rails laid on the level of the bottom of the pits, and is in reality a portable platform.

Repair shops. In the case of a number of systems it is usual to allocate a certain portion of the shed area to repair work, as for instance at Leicester, in which cases the shops are provided with the usual pits. This is not always the case in small undertakings. Referring to figure 161, the level of the repair shop is that of the bottom of the pits. In this case when it is necessary to transport car wheels for turning or grinding as the case may be, they must be lowered to the bottom of the pit. The arrangement in figure 161 is such that when a car has been run over a part of the track named the re-wheeling bay, just before the repair shop is reached, it is jacked up so that the wheels just clear the rails. At this position short sections of the rails just under the wheels are capable of lateral motion, so that a gap can be made for the axle to be dropped to the lower level by aid of the hydraulic jack. The wheels

can then be run into the repair shop. In some cases subsiding rails are provided for the hydraulic jack, but this is not always done.

Below the track level, that is in the pits, one lighting plug per car is usually provided alternating with the water supply. For the latter one water-cock per car length usually serves for two pits.

The repair shops at Bexley contain the following equipment and tools:

One $7\frac{1}{2}$ B.H.P. motor for driving shafting. One 12 in. double gap, triple geared lathe, 12 ft. 6 ins. bed, two pillar rests at one side for wheel turning, one saddle rest at the other side for turning commutators, etc. One $6\frac{1}{2}$ in. screw cutting gap bed lathe. One 3 ft. 6 in. radial drilling machine to drill up to $1\frac{1}{8}$ ins. diameter, with box bed. One small sensitive drilling machine to drill up to $\frac{7}{16}$ in. diameter. One double emery grinder with wet and dry stone drill grinder. One hydraulic wheel press. One tyre shrinking pit fitted with gas heating ring, and served by jib crane. One hydraulic lifting table. Two benches with vices, etc. One smith's hearth, anvil and smith's tools. One overhead runaway with carriage and 1 ton differential blocks. One furnace for melting white metal, etc. One armature drying oven. One armature stand. One armature binding wire drum on stand with brake. One set of moulds and mandrels for white metalling bearings. One crow for trolley booms. One pinion extractor. One air compressor for armatures and forge. One car wheel gauge. One pair of 36 inch outside callipers for wheels. One set of engineer's hand tools.

Overhead line tools. One tower wagon with adjustable table. One portable forge. One emergency trolley wire connector. One turnbuckle wire strainer. One pair of wire cutters. One hand saw. One tree clipper. One set of linesman's small tools, including spanners, mats, gloves, etc. A 20 ft. bamboo pole in two lengths for temporarily raising broken trolley wires is very useful on small systems in country districts when a horse is not immediately available for bringing the tower wagon.

Permanent way tools. One pitch boiler. Two rail carriers. One crow for bending rails (42 in. span). One rail gauge. One hand truck for 4 ft. $8\frac{1}{2}$ in. gauge containing:—drill clamps for vertical and horizontal drilling, one ratchet brace, one reamer and wrench for cleaning bond holes, one 3 ft. spirit level. One set of rods for clearing pipes to drain boxes. One set of picks, hammer, wedges, chisels, etc.

The car shed should be equipped with stand-pipes, hoses, nozzles, buckets and couplings for fire extinction. One sand drier and storage bin. One clock and time recorder. One portable fitter's vice. One "Little Sampson" truck. One mud-barrow. One pair of tressels for supporting car body with truck removed. Four small jacks for drop

wheel pit. One car shifter. Two girders to support motors when axles are lowered. One spring balance to read to say 40 lbs. for adjusting trolley pressure. One feeler to ascertain clearance between armature and pole pieces. The stores should contain scales to read to about 1 cwt. and in the case of large systems a weigh-bridge is provided.

The spare parts which are used in greatest quantity are trolley wheels, brake shoes, and controller fingers. It is advisable to provide a complete set of axles, wheels, gear wheels, pinions, armature bearings, motor suspension bearings, axle bearings, life guards, springs, bolts, nuts, etc., one armature, one trolley pole and standard for say every 12 cars or less. With regard to controllers it is advisable to store one complete controller for every 24 cars or less. In connection with overhead line stores such material as insulating bolts and ears might with advantage amount to 3 per cent. of that installed; trolley wire, guard wire, span wire, section insulators might amount to 1 per cent. of the installed quantity. Plate glass and moulded rubber strip should be stored to replace breakages. The general stores should include sand, salt, coal and coke, oil and other lubricants, sponges, wash-leathers, waste, rag, etc., one portable box containing quick-drying paint, one first-aid cabinet.

The staff at Bexley is as follows:

Permanent way. One superintendent, one paver, one platelayer, one labourer. Temporary men to meet special requirements.

Car shed and repair shop. One shed foreman, one overhead line man, one car fitter, one mate, one trolley and controller man, one boy for cleaning pits. A carpenter and painter are obtained from a local wheelwright for intermittent work.

Night staff. One brakesman, two washers.

Store. One storekeeper.

In addition there are the usual clerks in the General Manager's offices.

The heating at Bexley is provided by water heated by a sectional boiler having about 4000 square feet surface. The following temperatures are obtained for an outside temperature of 32° F.: Offices 60, car-shed proper 45, repair shop 55, paint shop 65, stores 55° F.

The nightly work in connection with each car consists in adjustment of brakes, examination of commutators, oiling of motor axles and trolley wheels, cleaning of controllers, and an inspection of the clearance between the armature and fields.

A weekly adjustment is made of the trolley pressure, which is 18 lbs. at the normal position of trolley head.

The motors are opened up and thoroughly overhauled every four months.

The Leicester Corporation Tramways have about 60 cars of the double-deck, single truck type, for which a main and two district sheds are provided. The main shed is laid out for 55 cars with provision for extension, and each of the two district sheds are laid out for six cars. The main depôt is located near the generating station on a site of about $4\frac{1}{4}$ acres. The entrance line is at right angles to the shed tracks. The first two tracks are each about 100 ft. long, and run into the fitting shop. The next two are each about 120 ft. long, and run into the carpenter's and painter's shops. The remaining nine, consisting of three about 130 ft., three about 150 ft. and three about 170 ft. long, run into the car shed proper.

The car shed proper has three bays each 35 ft. $1\frac{1}{2}$ ins. span and 21 ft. 6 ins. high to the eaves. The carpenter's shop is 80 ft. long and 35 ft. $4\frac{1}{2}$ ins. wide, and the painter's shop, which is an extension of the carpenter's shop, is 70 ft. long, the two being separated by Kinnear rolling blinds. The fitting shop will accommodate eight cars, and averages 130 ft. long, and is 41 ft. 6 ins. wide. It is 25 ft. high to the eaves from track level, and provision has been made for the erection of an overhead traveller. The pits are 4 ft. 6 ins. deep, and the tracks are laid on brick piers. Space is provided for a complete equipment of electrically driven machine tools, including 12 in. and 6 in. lathes, wheel turning lathe, radial drill, etc., and wood-working machines.

In addition there are an armature room, blacksmith's shop, brass and general stores, mess-room, recreation room, caretaker's house, offices and committee room, boiler house, oil store, and sheds for sand drying, tower wagon, cart, etc., and stables.

The stores and workshops are heated throughout on the low-pressure hot water system.

Large systems. The repair and maintenance of cars on some of the large systems are such that the work is no longer carried on in the car depôts, but in what are virtually carriage and engineering works. For instance, at Liverpool the carriage works now cover an area of 13000 square yards, and provide for the maintenance of the overhead system, rolling stock, etc. The description of such factories does not come within the scope of this chapter.

Conduit systems require special consideration on account of the plough. The plough is left free to move sideways, and the carriers are long enough to permit of it coming against the track rails. Hence the conduit can be placed at the side and the pit kept free for working purposes. The London County Council's Depôts are good examples of what is required in a large system.

Surface contact systems have car sheds similar to those used for overhead systems. The energy required to move the cars is supplied by a flexible insulated cable.

CHAPTER 12.

STORAGE BATTERY TRACTION AND REGENERATIVE CONTROL.

Storage battery traction. Probably the most obvious method of applying electricity to the propulsion of vehicles is by the use of storage batteries mounted on the cars, from which electric energy is supplied to motors on the driving wheels.

This system has very obvious advantages, chiefly the elimination of all external conductors such as trolley wires. At the same time, practical experience has demonstrated that the advantages are insufficient to set off the many drawbacks inherent in the system.

The main drawbacks are (1) the great weight of the batteries and (2) the cost of maintenance.

It is not proposed here to institute any detailed comparison between battery traction, and other systems, as the results of experience are sufficiently definite to make it unnecessary. It may be of interest, however, to give a little information as to the weights and capacities of batteries for such a purpose, as there are cases in which the choice of system is not obviously against the use of storage cells.

Weight in relation to output. In one way, a storage battery is very suitable for traction work, in that it can work over a very wide range of discharge; thus for example, a battery, of which the normal discharge current on the eight-hour rate is 180 amperes, can on emergencies or for very short times give out 800 amperes. This flexibility is precisely what is required for traction work in which the demand is very variable and intermittent. In dealing with the relation of weight to output, therefore, it is necessary to distinguish between normal and maximum rates.

For the sake of simplicity and for comparison with the method of calculation given below it will be best to consider batteries in relation to their capacity in terms of the three-hour discharge rate. This rate is the current at which the battery may be discharged continuously for three hours, at the end of which time the discharge will be complete. The capacity is thus defined as so many ampere hours.

The weights of batteries vary naturally according to the manufacture; but a fair average figure for heavy discharge cells complete with acid in lead-lined wood boxes is ·9 lb. per ampere hour (on the three-hour capacity). This figure represents a mean for the different types and sizes; for one manufacturer the weight per ampere hour may vary from 1·05 for a 450 ampere hour cell down to ·92 for a 2100 ampere hour cell; for another manufacturer from ·92 for a 600 ampere hour cell to ·76 for a 2000 ampere hour cell.

Two examples of recent battery locomotives may be quoted, viz. that on the Great Northern Piccadilly and Brompton Railway and that in the Chelsea power station of the Underground Electric Railways Co., London. In the former case there are 80 C.W. chloride cells with a normal discharge of 179 amperes and a maximum of 800 amperes, the plates being suspended in lead-lined wood boxes. The whole locomotive weighs 65 tons, of which the batteries alone account for 31 tons, and is driven by two 160 volt motors. The free running speed on the level when hauling a train of 60 tons is 7 to 9 miles per hour. In the Chelsea power station the locomotive contains 48 L.W. 5 chloride cells each with a three-hour capacity of 156 ampere hours, the whole battery weighing $2\frac{1}{4}$ tons. This locomotive is used for removing the boiler ashes which amount to about 40 tons per day.

When reckoning out the number of cells required in a battery, the normal voltage per cell may be taken at about 2 volts, the minimum being of course somewhat lower than this, viz. about 1·85. The weight per ampere hour is less for larger sizes, and it is therefore advantageous to choose a moderately low voltage.

Duration of discharge. A battery should not be discharged at a rate greater than $2\frac{1}{2}$ times the three-hour rate, although this may be exceeded on emergency. The size of the battery, therefore, to suit any given set of conditions may depend upon either the maximum demand, or the total capacity required. The maximum demand depends on the conditions of service and requires no fresh information for its determination; but the capacity of a battery on varying loads and intermittent service is a somewhat indefinite quantity.

The simplest method is to refer every discharge to the three-hour rate. Thus, supposing the cycle of operations to have been calculated out for a given set of conditions, a curve may be plotted shewing the current taken from the battery in terms of time, say in seconds. From this a second curve can be drawn expressing what may be called the "effective current" in terms of the time; this effective current being equal to the actual current multiplied by a factor to allow for the variation of capacity with the rate of discharge. Thus for instance, if the three-hour rate be 100 amperes, the capacity is 300 ampere

hours; the one-hour rate will be about 200 amperes, giving a capacity of 200 ampere hours. If, therefore, the one-hour current be referred to the three-hour rate, the current must be multiplied by a factor 1·5; thus, at the three-hour rate the capacity is

$$100 \times 3 = 300 \text{ ampere hours,}$$

and at the one-hour rate, the capacity expressed as the product of time into the effective current is

$$200 \times 1{\cdot}5 \times 1 = 300 \text{ ampere hours.}$$

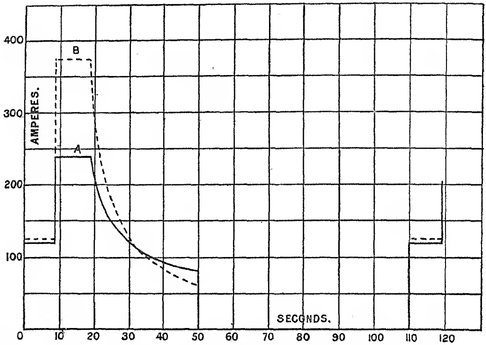


FIG. 164. Diagram shewing variation of current and effective current for a sample run with battery car.

The following set of factors may be taken, the currents being referred to the three-hour rate as unity:

Current	Factor	Current multiplied by factor, *i.e.* effective current
·5	·7	·35
1·0	1·0	1·0
1·25	1·14	1·42
1·5	1·27	1·9
1·75	1·4	2·45
2·0	1·5	3·0
2·25	1·58	3·55
2·5	1·65	4·12

For any particular case, then, the procedure is as follows:

Plot a curve of effective current in terms of the actual current for the battery in use; then prepare a curve of effective current in terms

of time, and integrate it. The area will be expressed in "effective ampere seconds," or if divided by 3600 in "effective ampere hours"; if this be divided into the three-hour capacity of the battery, the quotient will give the number of times the cycle may be repeated before the battery requires recharging.

Example. Take a battery with a capacity of 330 ampere hours at the three-hour rate of discharge; and let the cycle of operations be as represented in curve A, figure 164.

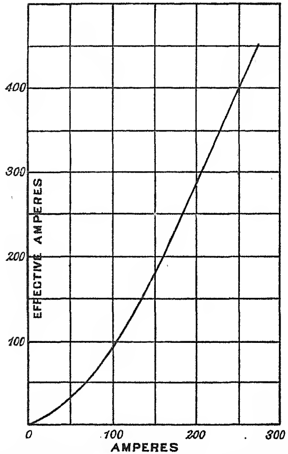


FIG. 165. Curve shewing variation of effective current in terms of discharge current of a battery.

Draw the curve of effective current as in figure 165 by multiplying the first and last columns in the foregoing table by 110 ($=\frac{330}{3}$). From the values given by this curve, draw the dotted curve B, figure 164, and integrate it.

The effective ampere seconds per cycle $= 8780$,
or effective ampere hours per cycle $= 2{\cdot}44$;

$\therefore$ the cycle could be repeated $\frac{330}{2{\cdot}44}$ times $= 135$ times,

and the discharge would last 135×110 seconds $=$ **4·15 hours.**

Regenerative Control.

Shunt and compound motors for electric traction. In previous chapters only one type of motor has been dealt with, viz. the series motor. This possesses so many obvious advantages for traction work that for several years no serious attempt was made to use any other type. It is, of course, not absolutely ideal, mainly because it is not readily adaptable to conversion into a generator whereby energy can be returned to the line when there is any necessity for checking the speed of the car either on an incline or when stopping on the level. A series motor can generate current if properly connected, and in fact is generally used for this purpose with what is generally called the "rheostatic" brake. Under these circumstances, however, the energy is dissipated in resistances and is not returned to the line. If a series motor be reversed so as to generate, and then connected to the trolley line, it is a practical certainty that it will generate an E.M.F. in the same direction as the line E.M.F., thus taking power from the line instead of returning it. This is a disadvantage inherent in the series motor.

With a shunt motor this drawback disappears as the excitation of the field is not dependent upon the direction of the current in the armature. In recent years several attempts have been made to take advantage of this feature, and there are now on the market two systems of regenerative traction involving the use of direct current shunt or compound motors.

Before describing these systems it will be advisable to discuss the difficulties and disadvantages attending the use of shunt motors for traction purposes, so as to understand more clearly the means adopted to overcome them.

Parallel running.—All shunt motors, except very small ones, are practically constant speed machines; if, therefore, two such motors which are similar are connected in parallel it is essential for a proper division of load that they should run at precisely the same speed. Now the two motors on a tramcar will only run at the same speed if the driving wheels have the same diameter; any difference, however slight, will cause an uneven distribution of the load between the two motors. This disadvantage can be mitigated to a certain extent by the use of a few series turns on the field; in this way the speed characteristic is modified sufficiently to ensure a proper division, and the advantage of the shunt connection is retained.

Difficulties due to variation of the field.—With shunt motors speed regulation is obtained by varying the strength of the field; with a

constant E. M. F. applied to the armature the speed is practically inversely proportional to the strength of the field. At certain points in the control cycle it is necessary to increase the field suddenly; for example, when changing the grouping of the armatures from series to parallel. This increase cannot be effected instantaneously, and if a fresh connection of the armatures be made before the full field strength is re-established there will be a rush of current, and consequently a severe jerk. Another drawback to the use of shunt regulation is the loss of energy in the shunt regulating resistances. This may be compared with the rheostatic loss in the series parallel control of series motors; in the latter case the loss is due to the main current but lasts only a short time, in the former the loss is due to a shunt current but continues as long as the car is running at its full speed.

Difficulty of adjusting the control for both accelerating and regenerating.—When changing the grouping from series to parallel certain conditions as to speed and strength of field in relation to the internal resistance of the motor must hold good if the change is to be effected smoothly. It will be seen on consideration that if the controller and resistances be adjusted for say the accelerating period, the adjustment will not be suitable for the retarding period.

Excessive rise of voltage if the trolley leaves the wire.—If when the equipment is generating current and returning it to the line, the connection between the motors and the line is broken either by the circuit breaker opening or the trolley leaving the wire, the retardation will cease and there will be a danger of the motors speeding up, if the car is on an incline, and generating a voltage far in excess of the line voltage. This may not only damage the motors, but may also burn out the lamps.

There are, as mentioned above, two systems on the market which make use of shunt or compound motors for the purpose of obtaining the advantages of regeneration; these are known, respectively, as the Johnson-Lundell system and the Raworth system.

Johnson-Lundell system. The distinguishing feature of this apparatus is the employment of the series parallel grouping to the greatest practicable extent. Each of the two motors has a doubly wound armature, the two windings being quite distinct and being connected to separate commutators. As far as the armatures are concerned, therefore, there are three possible groupings, four series, two series two parallel and four parallel. The object of this is by combining these groupings with a variable field to make the regenerative braking effective at the lowest possible speed. This is considered an important point in all types of brakes.

In the original arrangement of this system the fields were compound wound, but experience proved that the simultaneous adjustment of the control for accelerating and retarding was difficult. In the latest form this difficulty has been overcome by using the motors as series for accelerating and compound for regenerating. In this way full advantage is taken of the merits of the ordinary series parallel system in common use, and the gain due to regenerative braking is added. By this means also the greater part of the losses in the shunt resistances is eliminated, while at the same time, due to the use of the four distinct armature windings, almost all the rheostatic loss which occurs in the ordinary system is avoided.

The following figures will make this point clearer. In the original arrangement in which the motors were compound for all purposes, it was anticipated that there would be a gain over the ordinary series parallel system of 15 per cent. on account of the rheostatic loss and a further 25 per cent. on account of regeneration. As the result of elaborate tests at Newcastle-upon-Tyne, where an experimental car was run over the whole system for a long trial, it was found that the economy did not amount to more than 25 per cent. in all, and that the extra 15 per cent., although saved in one way, was lost in the resistances in circuit with the shunt winding. The system of control was in consequence redesigned in the direction mentioned above.

The apparatus which is required to carry out the control consists of the two motors with their doubly wound armatures, a controller of the ordinary barrel type, and a field changer.

The motors are of the four-pole type, and have laminated fields; these are wound with both shunt and series windings. The former winding on each motor is subdivided into four parts, which, by means of the field changer, are connected in parallel or in series; when the motors are accelerating these windings are in parallel and, with the series turns, act as the ordinary field winding of a series motor; when the motor is regenerating these windings are in series and form the shunt winding of a compound motor. These groupings are shewn clearly in the figures referred to below.

The field changer is shewn in figure 166 and consists of a cylinder carrying a number of contacts insulated as required which make connection with other fixed contacts after the style of a barrel controller. This cylinder has two positions, corresponding respectively to the series and the compound arrangement of the field coils; it is held in the former position by means of a spring and can be turned into the other position by a powerful magnet, which receives current from the platform controller whenever a press button in the controller handle is

pushed down by the driver. Thus the motors can be worked entirely as a series equipment, and can be converted into a regenerative system whenever the driver wishes.

The control diagram for both arrangements is shewn in figure 167. As will be seen, there is a preliminary step between "off" and notch 1 which provides for the insertion of a resistance in series with the motors; this is cut out almost immediately, leaving the four armature windings in series, and all the field coils arranged so as to obtain a maximum field strength. In notches 2 and 3 this field strength is reduced by shunting the field coils; in notches 4, 5 and 6 the armature windings are connected two in series two in parallel, the field strength

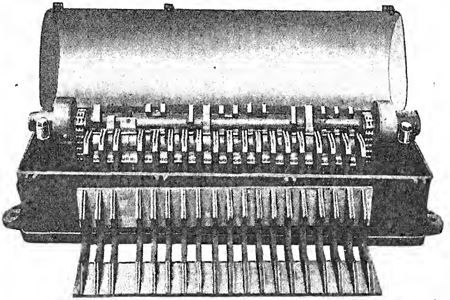


FIG. 166. Field changer of the Johnson-Lundell system of regenerative control.

being varied as before; and in notches 7, 8 and 9 the armature windings are all in parallel. In the regenerative arrangement the eight convertible field coils on the two motors are connected all in series, and form a shunt across the line voltage; the fixed series turns are arranged in opposition to these shunt windings so as to equalise the load and secure smoothness of operation, and the control is effected by changing the groupings of the four armature windings and varying the field strength by means of an adjustable shunt resistance. This latter resistance is not used at all when accelerating and can, therefore, be designed so that the changes of grouping do not give rise to any rush of current or the resulting jerk.

For the prevention of an undue rise of voltage if the trolley leaves the wire when the motors are regenerating on a down grade, a special device is attached to the trolley head. This consists of a spring

switch inserted in the lead which conveys current to the magnet of the field changer; the trolley head is not fixed rigidly to the upper end of the trolley pole but is hinged, and is capable of a small movement. If the head leaves the wire, the head, being no longer pressed down, springs up and opens the switch attached thereto; the motors, in consequence, are switched over into the series connection in which they cannot generate.

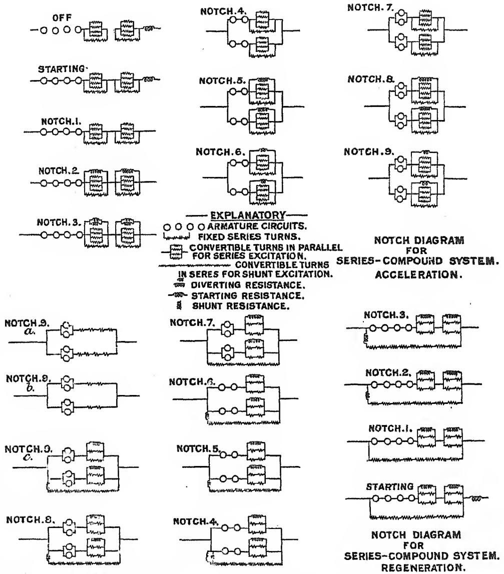


FIG. 167. Control diagram for the Johnson-Lundell system of regenerative control.

Various trials have been made of this system including that with a double bogie car on the London United Tramways between Shepherd's Bush and Southall, and several equipments are being constructed for the Norwich tramways.

The Raworth system of regenerative control. In this system the motors are compound wound both for accelerating and retarding. Of the compound winding the major portion is in shunt, the series winding being inserted for the sake of a proper division of load which is difficult with simple shunt windings.

The motors are very similar to ordinary series wound traction motors the armatures being in no way different, but compound field windings being substituted for the usual series windings; the controllers are also very similar to standard tramcar controllers. When the motors are connected in series the equalising of the load is, of course, unnecessary; when the motors are in parallel the series field turns must be in circuit. Provision is made on the controller for the ordinary rheostatic braking, for which purpose heavy series field windings are necessary; the series winding, therefore, has nearly as many turns as an ordinary traction motor of the same rating, but when the motors are connected in parallel as compound motors these series turns are shunted by a low resistance and carry only a small current.

This system of control differs in one respect from that already described, in that there are only two units for series parallel grouping instead of four. As a consequence a certain amount of control by means of series resistances is necessary before it is possible to regulate by varying the field strength. The complete cycle of operations performed by the controller is shewn in the diagram in figure 168, but before following through the combinations shewn therein, it is necessary to refer to the arrangements for the transition from the series to the parallel connection, when the motors are receiving current, and from parallel to series when generating.

It is one of the chief features of this system that it employs standard tramway motors modified only by rewinding the fields. The magnetic circuit is, therefore, not laminated throughout as is the case with the Johnson-Lundell system, and there is in consequence more delay in re-establishing the full field strength after it has been cut down for purposes of speed regulation. At the moment of making the change of grouping, provision must be made to prevent the rush of current into the armatures, and the most obvious method is to insert in the circuit a resistance which may be cut out after a short interval when the field has had time to rise. This in itself presents no difficulty; it is only when one considers that the order of carrying out this operation has to be different on turning the controller forward towards full speed and on turning it back for retarding that the difficulty appears. During the accelerating period resistance must be put in and then gradually cut out as the field rises; when passing through the same

change in the reverse direction, as the current is being generated by the motors, the same process must be gone through in the same order, although the controller barrel is moving in the opposite direction.

This requirement in the controller is fulfilled by providing two sets of steps or notches in the transition stage, one for each direction of rotation; arrangement is made so that the set which is not necessary is rendered inoperative, leaving the other set to perform its function.

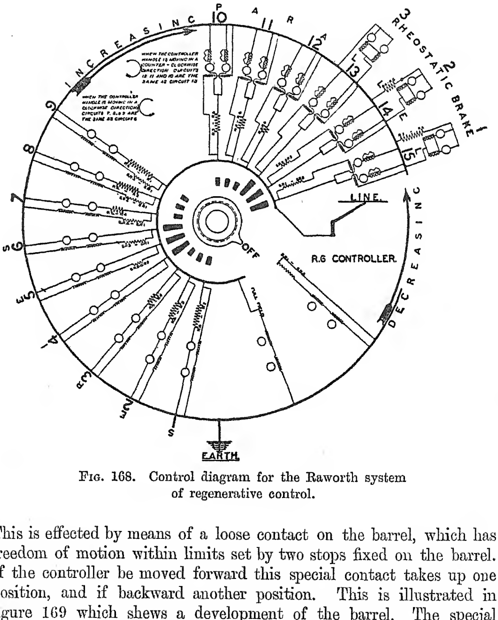


FIG. 168. Control diagram for the Raworth system of regenerative control.

This is effected by means of a loose contact on the barrel, which has freedom of motion within limits set by two stops fixed on the barrel. If the controller be moved forward this special contact takes up one position, and if backward another position. This is illustrated in figure 169 which shews a development of the barrel. The special contact is marked X in this figure, and takes up the position shewn in full lines when the controller is moved forward, and that shewn in dotted lines when moved backward.

The cycle of operations is shewn in figure 168. The shunt winding is first connected to the line, and then in position 1 the armatures are put in series with some resistance across the line voltage. In positions 2 and 3 this resistance is reduced, and in position 4 it is cut out altogether. This is the first economical running position and the speed corresponding thereto is from $3\frac{1}{2}$ to 6 miles per hour according to the motors chosen; this represents also the minimum speed at which the motors can be used for purposes of regeneration. In positions 5 and 6 the field strength is reduced, the final value being about half the maximum. If the driver wishes to proceed into parallel he moves the controller handle round to position 13, in so doing passing positions 7, 8, 9, and 10, 11, 12. With this direction of motion no change is effected by positions 7, 8 and 9, the contact X (figure 169) short circuiting the resistance contacts. On leaving position 9 the

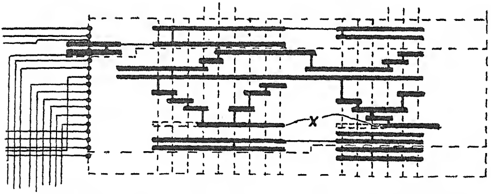


FIG. 169. Development of the controller barrel for the Raworth system of regenerative control.

circuit is opened and on position 10 the armatures are rearranged in parallel each in series with its series field winding, and resistance is inserted in the main circuit, which is cut out in positions 11, 12 and 13. The two remaining positions provide for the attainment of the full speed by means of weakening the field. The reverse operation for regeneration can easily be followed from the diagram.

This device of the moveable contact on the barrel enables the motor circuit to be opened when there is no external resistance in it. The inventors claim that this prevents flashing at the controller contacts which would otherwise occur.

For rheostatic braking the controller is turned past the "off" position in a counter-clockwise direction, thereby turning round simultaneously by means of gearing a small barrel immediately below the reversing barrel. This rearranges the field connections so that the motors may generate on to resistances in the ordinary way.

The arrangement in this system for preventing an excessive rise of voltage consists of a special form of automatic circuit breaker connected as shewn in figure 170. In this figure the circuit breaker is marked X and consists of a switch arm pivoted at E making contact with C or F according to its position. Normally when the trolley is in contact with the line connection is made between C and E; if the trolley leaves the line or the overload circuit breaker opens, and in consequence the motor generates an excessive voltage, the switch X is tripped by means of an increase of current in the coil A. When the

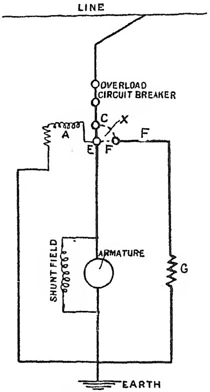


FIG. 170. Diagram of special automatic safety device for the prevention of excessive rise of voltage. (Raworth.)

switch is tripped the arm flies over and makes connection between E and F and thus closes the motor circuit through the resistance G. Current is therefore generated in this circuit and checks the speed of the car.

Various tests have been made with this system of regenerative control, particularly in Bristol and on the South Metropolitan Tramways, also at Devonport. In Bristol official tests were made by comparing two cars, one fitted with standard series motors and the other with Raworth regenerative control. As the result of a series of runs over about 44 miles of track it was found that the energy consumptions were as follows:

With the standard series motors ... ... 1·15 B.T. units per car mile
With the Raworth regenerative control ... ·871 B.T. unit ,,
that is, a saving of 24 per cent. in favour of the latter.

Similar results were obtained in the other cases, the figures varying between 24·3 and 28·7 per cent.

General remarks on regenerative systems. It may be a matter for surprise that, in view of the obvious advantages obtained by means of some system of regenerative control, these systems have not come into more general use. This may be partly accounted for by the difficulty experienced by every new invention in forcing its way to the front; but it may be advisable to state the pros and cons as they appear to many tramway engineers.

The advantages are, of course, chiefly the economy of electrical energy, and secondly the saving of the wear and tear on the brake blocks.

The disadvantages generally urged against the innovation are, that the apparatus is more complicated, and consequently its maintenance cost is greater; that the heating current of the motors is increased and consequently larger motors are necessary, which involves greater first cost.

With regard to the disadvantages it must be admitted that the new apparatus is somewhat more complicated than that in general use, but it is certainly not so intricate that it should act as a deterrent to any engineer. The increased cost of maintenance is a point which cannot very well be proved or refuted; time is necessary before this question can be finally settled. There can be little doubt that, all other things being equal, the heating current of the motors in the regenerative systems is greater than in the ordinary series parallel system. This may fairly be urged against the application of these systems to railway work, but in tramway work there is certainly a tendency at present to employ motors that are too big for the requirements of the case as far as temperature rise alone is concerned, for the sake of keeping down the maintenance cost. In this case the argument that regenerative control would require an increase in the motor capacity falls to the ground.

CHAPTER 13.

THE DIRECT CURRENT RAILWAY MOTOR.

The railway motor as an extension of the tramway motor. The first electric railways differed very little from electric tramways, and it was perfectly natural, therefore, that the first railway motors should be designed on the same lines as tramway motors. Modifications became necessary as the electric railway developed, such modifications being almost entirely due to an increase in the size of the motors. So long as the output was limited to about 35 or 40 H.P., the space available for the motor was sufficient to give the designer a fairly free hand. When, however, the demand arose for railway motors up to 150 or 200 H.P., which should be mounted on a standard gauge truck with a driving wheel of 3 feet or 3 feet 6 inches diameter, it became evident that the mechanical design must be modified.

The chief modification consists in the arrangement of the bearings. It becomes absolutely necessary that these should be, so to speak, countersunk into the armature. The arrangement adopted is shewn in figure 171, in which it will be seen that the bearing at the pinion end projects inward under the armature end connections and the bearing at the commutator end projects inward into the hollow cone formed by the commutator body, or the spider.

Many other modifications have been devised from time to time, some of which have been reflected back upon the tramway motor, such for instance as details of lubrication and methods of armature and field construction.

As exemplifying recent types of railway motor of the direct current geared class, the following may be quoted from a description of a 200 H.P. Westinghouse railway motor:

Two brush-holders are used, arranged under the large opening in the field frame. Each brush-holder has three carbon brushes 3 inches wide by $1\frac{1}{2}$ inches thick. Copper clips are bolted to the carbons, and these clips are connected by flexible shunts of ample capacity to the body of the brush-holder.

The commutator is made of copper bars, rolled and hard-drawn, having solid necks raised above the surface of the commutator, with milled slots, into which the armature bars are thoroughly soldered. The mica between bars is ·025 inch thick, and is of such hardness as to ensure its wearing at the same rate as copper. The mica between the bars and the rings is 1/16th inch thick, and a mica ring is placed between the bars and the commutator spider. The commutator is $16\frac{7}{8}$ inches in diameter, and the bars are of such depth as to allow a reduction in diameter of 2 inches.

The field coils are made of copper strip wound on edge. The insulation between turns consists of asbestos, held in place by shellac and baked under heavy pressure so that the coil and insulation make a solid mass. The complete coil is placed in a curved metal case, from

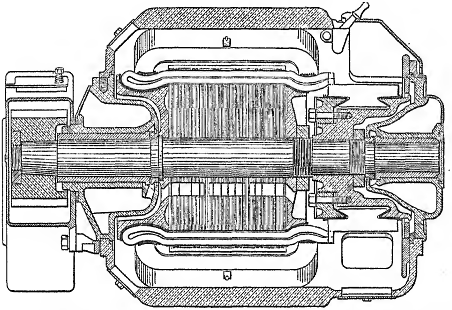


FIG. 171. Arrangement of bearings in a large direct current geared railway motor. (Dick Kerr 150 H.P.)

which it is insulated by asbestos and mica. This construction makes a coil that is fireproof and waterproof. The curvature of the coil and the case is such as to fit the curvature of the field.

The armature is of the slotted drum type, built on a cast-iron spider, which is extended to receive the commutator spider. The core is built up of sheet steel of the highest magnetic quality, with ventilating ducts. The core is 20 inches in diameter by 13 inches long. The winding consists of copper strips formed and insulated before being placed in the slots. The ends of the coils outside the armature core are banded firmly on an insulated extension of the end plate.

The armature insulation consists essentially of mica, which extends between turns at all points. The mica is protected by a sufficient amount of fibrous material, treated with a moisture- and oil-proof compound to ensure it against deterioration.

The completed motor will stand a momentary puncture test of 4500 volts alternating or 3000 volts for one minute between winding and motor frame.

The field and armature leads are of best quality flexible cable, rubber insulated.

The motor has a split-field frame, not hinged, so arranged that by removing the nuts of the clamp bolts, the top half-field can be readily lifted off for internal inspection and for removal of the armature or field coils without removing the lower half-field from the car truck. When the top half is removed, the lower half remains suspended from the axle by stirrups, which are permanently attached to the axle bearings. The armature bearings are contained in housings which are securely held between the halves of the field frame, being tongued and grooved to the frame and securely dowelled.

The field frame is made of cast steel, of a quality best suited to the purpose. There are four poles bolted to the yoke, made of laminated steel held between heavy end plates secured by rivets.

Bearing boxes are phosphor bronze, lined with babbit-metal well grooved for oil; the armature bearings are provided with drip grooves, into which waste oil is thrown by wiper rings on the shaft. The armature bearing at the pinion end is $4\frac{3}{4}$ inches by 10 inches, and at the commutator end 4 inches by 7 inches. The axle boxes are made to suit a $6\frac{1}{2}$ inch axle, and are about 14 inches long.

Armature and axle bearings are lubricated by oil fed to the journals by waste; the oil boxes being so formed that the waste will pack itself against the journals. Oil box covers will be lipped and hinged, and fitted with springs.

The gears are solid, of cast steel with cut teeth to be pressed on the axle. The pinions are of forged steel with cut teeth. They are a taper fit on the shaft. The gears are 5-inch face with a diametral pitch $2\frac{1}{2}$ per inch.

Electrical design of direct current railway motors. The electrical design of direct current railway motors is based upon precisely the same principles as that of tramway motors, and their performance curves are calculated in the same way.

As already mentioned, the limitations of space prevent any great extension of the axial dimensions. Thus the components of axial length are as follows:

1. Clearance between driving wheel and gear case.
2. Width of gear case.
3. Clearance between gear case and motor case.
4. Thickness of motor case.
5. Clearance between motor case and armature end connections.
6. Armature end connections at pinion end.
7. Armature core.
8. Armature end connections at commutator end.
9. Commutator.
10. Clearance between commutator and motor case.
11. Thickness of motor case.
12. Clearance between motor case and driving wheel.

For a standard gauge truck the sum total must be less than 4 feet $8\frac{1}{2}$ inches by an amount approximately equal to twice the thickness of the wheel flanges. With these limitations the maximum length of the armature core for large railway motors is about 13 inches.

Forced ventilation. In some cases it is found worth while to instal the necessary plant for providing forced ventilation to the motor. An example of this occurs in the locomotives supplied by the British Westinghouse Company to the Metropolitan Railway, and other cases have occurred on the Continent.

The effect of forced ventilation will be different according as the one hour rating or the continuous capacity is in question. As already explained, in dealing with the heating of the tramway motor, the one hour rating depends partly on the heat absorption of the armature and field coils and partly on radiation. Of these only the latter will be affected by increased ventilation, whereas the continuous capacity is determined solely by radiation.

Direct coupled motors. So far geared motors only have been considered. With gearless motors, which are connected either directly or through spring couplings to the driving axles, the case is quite different and the same limits do not hold good.

Direct coupled motors are, thus, of two classes, viz.: those in which the armature is built directly on the driving shaft, and those in which the armature is built on a hollow shaft surrounding the driving axle and coupled to it by means of a spring coupling, sufficient clearance being allowed between the hollow shaft and the axle for the relative motion due to the springs.

Each class has its own advantage. In the first the axial space available for the armature and commutator is as great as possible, as there is no allowance to be made for bearings or gear wheel. In the second the disadvantage of having the whole motor supported from the track without springs is eliminated, at the expense of the allowance of space for two bearings and the spring coupling.

Central London Railway locomotive motor. This motor is a good example of the first class, and many particulars in connection with it have been published from time to time*. As shewing the contrast between this motor and a geared motor for a truck of the same gauge the dimensions of the armature core of the gearless motor are $22\frac{1}{2}$ inches diameter by 28 inches long.

The cross-section and outline of this motor are shewn in figure 172.

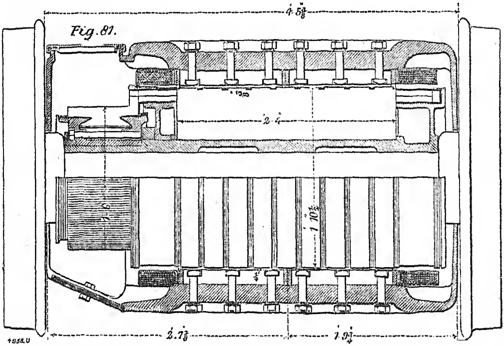


FIG. 172. Cross-section of Central London Railway gearless motor.

Motors with elastic couplings. These have been used on the Continent, and an example is furnished by the Valtellina Railway in the North of Italy. In this case the motors are three-phase motors. This method was also used in the United States some years ago, the first electric locomotives on the Baltimore and Ohio railway being equipped with motors built on a sleeve surrounding the driving axles with a sufficient clearance.

Geared motor with elastic coupling. Such a motor is in use on the Fayet-Chamounix line in Switzerland. This motor is peculiar

* *Traction and Transmission*, vol. 7, p. 285 and elsewhere.

in that it is suitable for a narrow gauge (1 metre), and yet is not subject to the limitations of axial dimension as already explained. Moreover the whole weight of the motor is spring-borne, the connection between the motor and the driving axle being elastic.

The solution of the difficulty in this case has been found in the adoption of bevel gearing. The motor is mounted on the truck with its axis parallel to the rails instead of at right angles as usual. On the shaft of the motor is a bevel pinion which gears with a bevel wheel, the gear ratio being 4 : 1. The bevel gear wheel is keyed to a sleeve surrounding the car axle, and carrying one half of an elastic coupling by which connection is made with the driving wheels.

New York Central and Hudson River Railroad Locomotive. A great disadvantage of the gearless motor mounted directly upon the driving axle is that an excessive dead weight or unspring-borne load is put on the track. The result is increased wear and tear at the rail joints, and great stresses in the truck and also in the motor itself. To minimise this trouble the General Electric Company of America devised a novel method, which consisted of building the armature directly on the driving axle and mounting the field magnets on the truck with the usual springs. With the ordinary design of motor the vertical motion of the armature relative to the field magnets would have resulted in the two parts coming into contact, and consequently the magnet poles were so shaped that the armature was free to move vertically without coming into contact with the field. The general features of the design are shewn in figure 173.

As will be seen from this sketch the motor is of the two-pole type, the axis of the magnetic field being horizontal. The poles, instead of being curved so as to embrace the armature, are almost flat. Thus the armature diameter is 29 inches, the distance from pole piece to pole piece along the axis being $30\frac{1}{2}$ inches and the distance between pole tips being $29\frac{1}{4}$ inches. The armature can therefore be taken out between the pole tips with $\frac{1}{8}$ inch clearance on each side.

The electrical design is of considerable interest. In a general way, without considering the special features, it would be said that the two-pole arrangement was bad for the following reasons. Very great distortion of the magnetic field, due to armature reaction and the consequent difficulty of commutation. Long commutator necessitated by the possibility of only two rows of brushes. Inefficiency due to long armature end connections. Very heavy magnetic circuit.

Dealing with these points seriatim, it may be observed that the magnetic distortion of the field is practically prevented by the shape of the poles. The cutting back of the pole tips creates a large neutral

zone. Commutation is also influenced by making the ratio of field ampere turns to armature ampere turns high and by the use of a chord winding on the armature, though these features are common to most traction motors. The design is said to be so far successful in this respect that the motors will commutate perfectly up to 1000 amperes at 600 volts.

With regard to the commutator it is not usual in direct current motors to have more than two rows of brushes, and moreover the space available in an axial direction is ample.

Long end connections are, naturally, unavoidable with a two-pole motor.

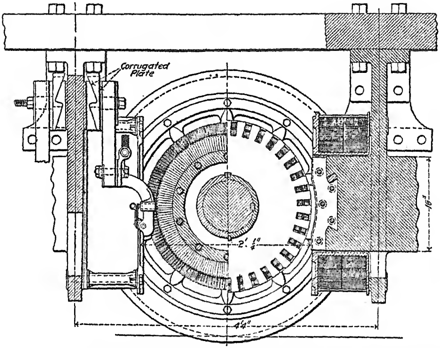


FIG. 173. Cross-section of gearless motor on the New York Central and Hudson River Railroad Locomotive.

The weight of the magnetic circuit is partially reduced by the arrangement of the four magnetic fields in series. Apart from this, however, it is necessary for the purpose of adhesion that the locomotive should be sufficiently heavy. In other cases the weight has been made up by adding heavy beams or girders which had no other function than simply to increase the weight on the driving wheels. In this case, therefore, it cannot be urged as a disadvantage that the extra weight has been put into the magnetic circuit.

As shewn in the sketch the magnetic field passes through all four motors in series. The arrangement whereby all the motors of a locomotive have identically the same field would have certain drawbacks.

In the first place, any inequality in the diameter of the driving wheels would cause very considerable differences in the division of the load between the separate armatures. In the second place, if any one of the armatures developed an internal short circuit, nothing could be done to prevent the burning out of the defective armature when the other motors were in use. These drawbacks are, at all events, partly met by the magnetic cross connections from the magnet cores between the armatures to the common magnetic return. Each of these cross connections will take from 40 to 50 per cent. of the total flux.

Performance curves for this motor are given at the end of this chapter in figure 182.

The tendency towards higher voltage. The steadily growing competition of alternate current traction systems has led designers to look into the problem of producing motors suitable for use on high voltage direct current circuits.

The raising of the voltage of a direct current motor involves two dangers; firstly the danger of breakdown from the windings to the body, and secondly the danger of flashing from brush to brush round the commutator due to bad commutation.

The first danger is not so serious as the second, and can be met by the simple process of using sufficient thickness of insulation; the second requires very careful study, and special steps must be taken to ensure that the commutation may be better even than in the standard 500 volt traction motors.

There are two ways of dealing with the question of commutation, viz. (1) the provision of commutating poles with the usual proportions of slots, polar angle, etc., and (2) no commutation poles but special precautions in the proportions and constants of the motor.

An example of each of these methods is given by the 130 H.P. 1000-volt traction motor by Messrs Siemens-Schuckert and the 75 H.P. 1500-volt motor* built by Messrs Joh. Jakob Rieter and Co., of Winterthur, Switzerland.

The 130 H.P. 1000-volt motor is shewn in figure 174, and, as will be seen, is a 4-pole machine with four commutation poles. The windings of these commutation poles are so arranged that they do not encroach on the space available for the main poles with their coils. To prevent any possibility of arcs being set up between the commutator and the case, the latter is lined with asbestos in the neighbourhood of the commutator.

The 75 H.P. 1500-volt motor is designed with special attention to the commutation constants but with no special poles. In particular

* *Elektrische Bahnen und Betriebe*, September 23, 1905.

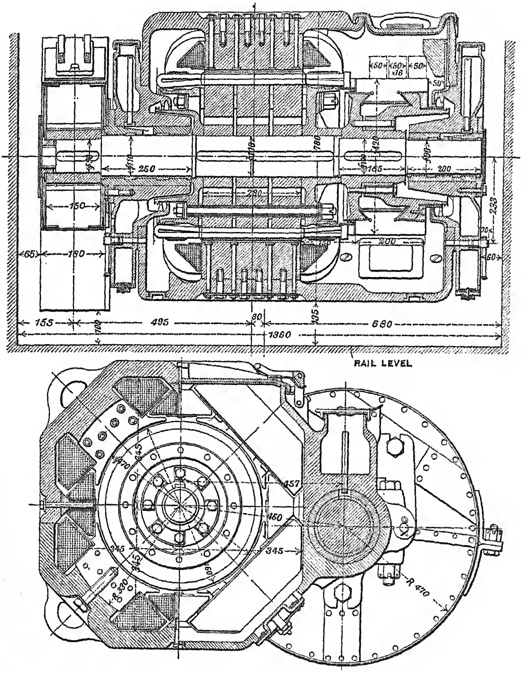


FIG. 174. Cross-section of 1000-volt 130 H.P. direct current motor on the Cologne-Bonn railway.

the number of commutator parts is very high for a machine of this size, and the slots are, of course, open at the top. Similarly, the polar angle is only 67 per cent. of the pole pitch, thus providing a broad neutral space for commutation. The insulation, also, has been specially designed, and, in addition to the usual coverings of the windings, a lining of 1 mm. thickness of micanite is provided. The windings withstood a test of 10000 volts alternating for one hour, but broke down at 12500 volts after 10 minutes.

It is stated that 16 of these motors are being built for the Bellinzona-Mesocca Railway.

Curves for this motor are given at the end of the chapter in figure 176.

Limit to the size of railway motors. It is interesting to notice that there are definite limits to the size of railway motors from the point of view of possible requirements. The limit is not so much in the direction of horse-power as in the direction of tractive force.

For reasons of wear and tear of the track it is very unusual for the load on a pair of wheels to exceed 20 tons, and more frequently the limit in England is 16 to 17 tons. In the United States higher loads are admitted occasionally. Taking however a load of 20 tons and an all round coefficient of adhesion of one-fifth, it is obvious that no motor, unless it is coupled to more than one pair of wheels, will be required to exert a tractive force greater than 4 tons or say 9000 lbs.

Such a pull would seldom be required at any speed greater than 35 miles per hour, and the maximum output will therefore be $\frac{9000 \times 35 \times 1{\cdot}466}{550} = 887$ H.P. Of course higher speeds may in future be required, but unless a special track with extra heavy rails be laid, the tractive force will not exceed the figure given above and will generally be less.

Flashing across of traction motors. Attention has been directed recently to one particular trouble to which direct current traction motors are liable, viz. that of flashing round the commutator from one brush-holder to the other. This usually takes place only when the supply has been interrupted while the motor is working and is reestablished after a very short interval.

The trouble is generally attributed to the fact that when the circuit is reestablished the magnetic field in the motor does not rise to its proper value instantaneously. As a consequence the back E.M.F. in the armature is also below its proper value, and hence the initial value of the current is higher than the normal. This excessive rush of current gives rise to sparking at the brushes and may set up flashing across from one brush-holder to the other.

The reason for the comparatively slow rise of magnetism is stated to be the fact that part of the magnetic circuit is of solid steel, in which eddy currents are produced which tend to prevent the rise of the field. Mr Lamme has suggested other causes which may contribute to the delay in the rise of the field, viz. the local short circuit in the part of the armature winding under the brushes, and the heavy metal frames which surround the poles for the purpose of supporting the field coils.

There may, under certain conditions, be another cause, viz. surging in the distributing conductors. If in a circuit containing a uniformly distributed inductance L and capacity C a current of x amperes be flowing; and if this circuit be suddenly opened a wave of E.M.F. will travel along the line and will be reflected back in such a way that the voltage at the point of opening may rise to a value greater than the normal voltage of the supply by an amount equal to $x\sqrt{\frac{L}{C}}$, the various quantities being expressed in proper units. It is possible, therefore, that under favourable conditions there may be a sudden application to a motor of a voltage for which that motor was never designed.

This trouble is stated to be accentuated by the adoption of voltages higher than 500 volts and is not confined to the motors on the train, but sometimes makes its appearance in the sub-stations at the commutators of the rotary converters, and this has been used as an argument against the adoption of high voltage direct current systems. Experience, however, is necessary to prove whether the argument is sound or whether the trouble cannot be overcome by suitable design of the motors. On the Cologne-Bonn railway, equipped by Messrs Siemens-Schuckert, where the voltage is 1000 direct current, there has not been a single instance of flashing round; and it is possible that, as more experience is gained, less will be heard of this difficulty.

Standard gauges. It may be useful for cases where traction motors are designed for use in foreign countries to give a table shewing the various standard gauges.

Country.	Gauge.
Great Britain.	4 ft. $8\frac{1}{2}$ in.
,,	Light railways sometimes 3 ft. 6 in. or 3 ft.
Ireland.	5 ft. 3 in.
,,	Light railways 3 ft.
Austria.	State railways 1·435 metre = 4 ft. $8\frac{1}{2}$ in.
Belgium.	State railways 1·435 metre = 4 ft. $8\frac{1}{2}$ in.
,,	National light railways mostly 1 metre.
France.	State railways 1·45 metre = 4 ft. 9 in.

Country.	Gauge.
Germany.	State railways 1·435 metre = 4 ft. 8½ in.
Holland.	1·435 metre = 4 ft. 8½ in.
Italy.	Chiefly 1·435 metre = 4 ft. 8½ in.
Norway and Sweden.	1·435 metre = 4 ft. 8½ in. and 1·067 metre = 3 ft. 6 in.
Portugal.	1·67 metre = 5 ft. 6 in.
Russia, including Finland.	1·523 metre = 5 ft.
Russian Poland.	1·435 metre = 4 ft. 8½ in.
Spain.	1·67 metre = 5 ft. 6 in. or 1 metre.
Switzerland.	State railways 1·435 metre = 4 ft. 8½ in.
Turkey.	1·435 metre = 4 ft. 8½ in.
India.	State railways mostly 5 ft. 6 in.
Japan.	Imperial Government railways 3 ft. 6 in.
Egypt.	State railways 4 ft. 8½ in.
South Africa.	3 ft. 6 in.
United States.	4 ft. 8½ in.
Canada.	4 ft. 8½ in.
New Zealand.	3 ft. 6 in.
New South Wales.	4 ft. 8½ in.
Queensland.	3 ft. 6 in.
South Australia.	5 ft. 3 in.
Western Australia.	3 ft. 6 in.

For further information see the *Universal Directory of Railway Officials.*

Sample performance curves of direct current railway motors. A number of performance curves are given below for a wide range of direct current railway motors. These curves may be useful in estimating, and may be modified for different gear ratios and diameters of driving wheels by simple proportion. As a general rule it may be taken as approximately true that the root mean square current* per motor should not exceed half the current corresponding to the one-hour rating.

* See pp. 14 and 379.

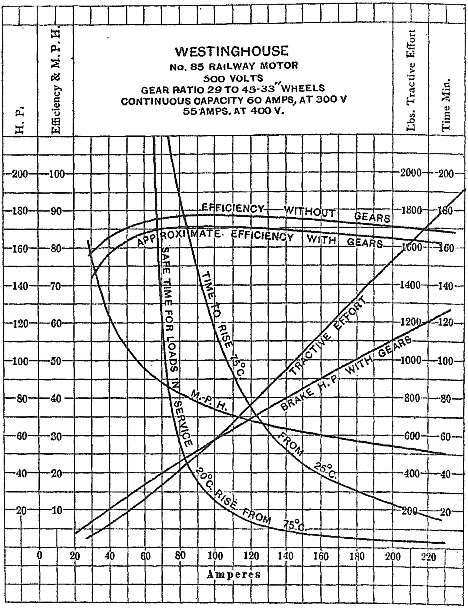


FIG. 175. Westinghouse 75 H. P. geared railway motor.

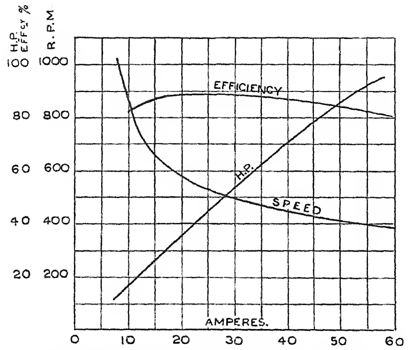


FIG. 176. G.B.S. 175, 1500-volt 75 H.P. geared railway motor. (J. J. Rieter & Co.)

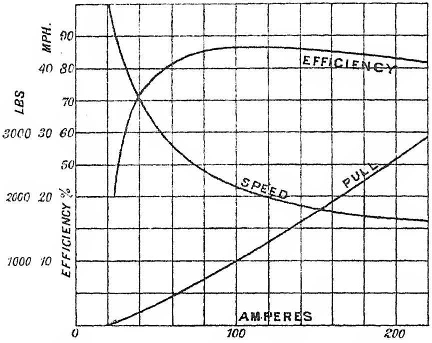


FIG. 177. G.E. 73 A. 500-volt 100 H.P. geared railway motor. Gear ratio 65 : 24=2·7. Wheel diameter 34″.

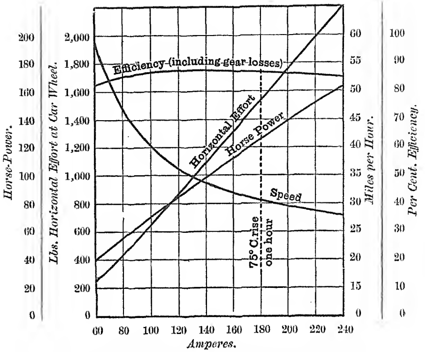


FIG. 178. Dick Kerr 600-volt 125 H.P. geared railway motor.
Gear ratio 41 : 19 = 2·16. Wheel diameter 36″.

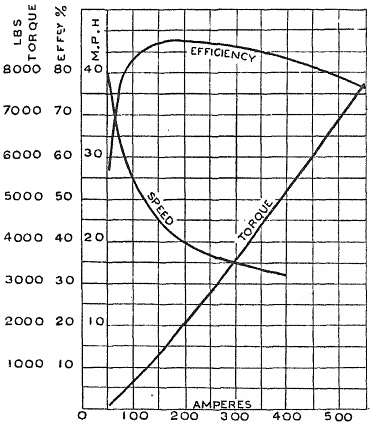


FIG. 179. G. E. 500-volt 150 H.P. geared railway motor.
Gear ratio 54 : 19 = 2·84. Wheel diameter 33″.

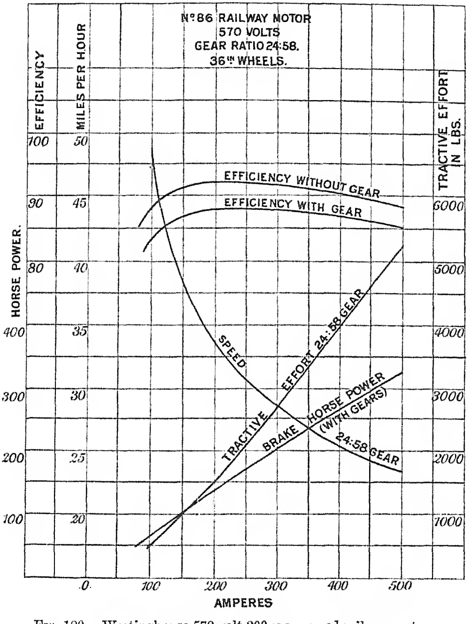


FIG. 180. Westinghouse 570-volt 200 H.P. geared railway motor.

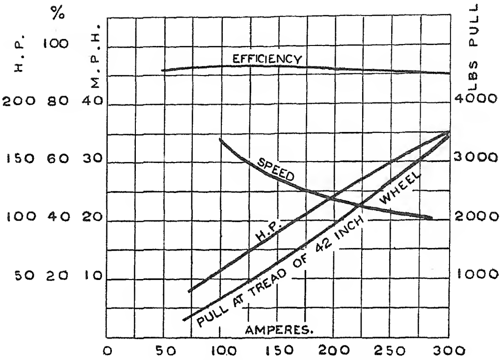


Fig. 181. G.E. 56 A. gearless railway motor, 500 volts.
(Central London Railway.)

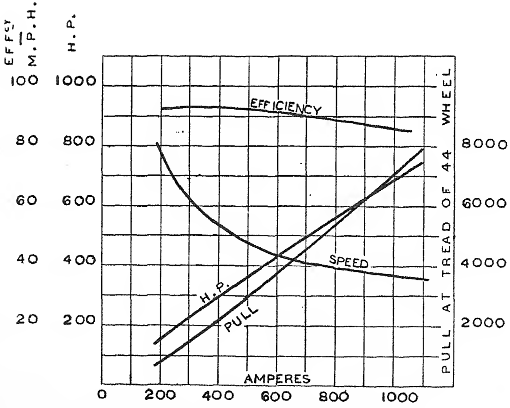


Fig. 182. N.Y.C. and H.R.R. Locomotive, 600 volts.
G.E. 84 gearless railway motor.

CHAPTER 14.

THE CONTROL OF THE DIRECT CURRENT RAILWAY MOTOR.

General. In precisely the same way as the railway motor is the outcome of developments from the tramway, so the railway controller is an extension of the tramcar controller to meet the fresh conditions imposed upon it. The process of extension and modification has proceeded much further in the case of the controller, so that what may, perhaps, be called the final type is more widely separated from the original than in the case of the motor.

The development has followed, as it was bound to do, the development of electric railway work in general. At first, electric railways were merely modified tramways, and consisted of single cars running over private ground. The fact that the track was not laid in the public streets removed many of the restrictions to which tramcars are subject. The absence of other traffic permitted the use of higher speeds, which in turn necessitated heavier cars. Both these results produced their own effect on the motors, so that, whereas two 30 H.P. motors sufficed for a tramcar, under the new conditions two 50 or 75 H.P. motors were required.

The next step in the development consisted in the formation of electric trains hauled by an electric locomotive. Such trains were used on the City and South London Railway, which was the first example of what are now called "tube" railways.

The first stage in the development only necessitated tramcar controllers of larger capacity, whereas the second stage introduced new conditions. Not only were the motors increased, but, further, the controller was mounted in a locomotive. This gave rise to structural differences.

Further developments took place in the composition of the trains, in some cases there being a locomotive passenger car at each end of the train, and in other cases trains of six or seven carriages being coupled to a single locomotive.

As time went on railway controllers got larger and larger, until the system was introduced of making up the trains of a number of "motor-cars" and a number of trailer cars with the object of splitting up the train into several component parts, each part being capable of self-propulsion.

This system required and was made possible by the introduction of the "multiple unit control system," in which each motor-car was equipped with its own motors, controllers and resistances, and all the controllers were fitted with devices whereby they were all worked simultaneously by the driver in the front of the train.

This new condition at first gave rise to numerous schemes for connecting the individual controllers; but later the controllers themselves have been modified to meet the fresh requirements, by the substitution of a number of separate switches, each one controlled electrically by the driver. These switches being opened and closed in their proper order effected all the changes usually made by the controller in the connections of the motors; and, by connecting similar switches on different cars to the same train wire, any number of cars could be governed simultaneously.

Before going more fully into the details of the various systems, it will be best to consider two points which are at the basis of all electric switches, viz. the dimensions of a contact for a given current, and the arc formed when a circuit is opened.

Dimensions of a contact. When the contact of a switch is formed by two plane surfaces pressed together it is customary to limit the current flowing across that surface to about 100 amperes per square inch. This value must, of course, depend on the facilities provided for conducting away the heat generated; but it holds good for the blades of "knife" switches.

It is impossible, however, to ensure perfect contact over the whole area, so that the real current density is always much greater than the nominal. This fact, coupled with the consideration of the radiating surface, helps to explain how it is that the contact between the tramway controller finger and the barrel is only a line.

Some experiments were made by Messrs Siemens Bros. a few years ago at Woolwich, and it was found that it was possible to pass a current of 800 amperes continuously through a line contact $\frac{7}{8}$ inch long without fusing or overheating provided the contact pieces were sufficiently massive. The contacts in question had dimensions as in the sketch figure 183.

Lighter contacts of the $\frac{3}{4}$ inch width, and only $\frac{1}{8}$ inch thick, would carry 200 to 240 amperes in the open.

Much larger intermittent currents can be dealt with; for instance, a current of 950 amperes was passed for five seconds every three minutes through a contact area of $\frac{1}{8}'' \times 1''$.

Such figures are, of course, beyond the limits of practice; but they are useful in shewing that large currents can be passed through very small contact surfaces under favourable conditions.

In most cases the current carrying capacity of the finger is not the most important particular. If the above finger $\frac{3}{4}$ inch wide and $\frac{1}{8}$ inch thick had frequently to break a current of 240 amperes at 500 volts it would not last very long. The influence of the arc on the contact must therefore be considered.

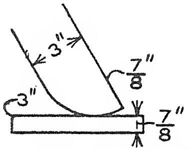


FIG. 183. Experimental contact piece.

The arc formed on opening a circuit. The magnitude of an arc is sometimes measured by the product of the current flowing before the circuit is opened and the volts across the switch after the opening. Thus, for instance, if the current to be broken is 20 amperes and the electromotive force in the circuit is 500 volts, the arc may be called a 10 kilowatt arc.

Such a method is, however, misleading, as it takes no account of the inductance in the circuit, which undoubtedly has a great influence on the destructiveness of the arc.

For example, suppose a current C to be flowing in a circuit containing an inductance L but very little resistance. Then when the circuit is opened practically the whole of the energy stored in the inductance will be dissipated in the arc. This energy is $\frac{1}{2}LC^2$.

To take a particular case, let the current be 100 amperes and the inductance such that a total flux of 2×10^6 C.G.S. lines is included in 200 turns, each carrying the full current, the stored energy is

$$\frac{1}{2}\left(\frac{2 \times 10^6}{10} \times 200\right) \times 10^2 = 200 \times 10^7 \text{ ergs} = 200 \text{ watt seconds.}$$

It is obvious, therefore, that the presence of inductance should be taken into account. On the other hand also it is necessary to take into account any back E.M.F. there may be in the circuit due to, say, an

armature rotating in a magnetic field. Take the case of a series wound motor; the applied voltage is equal and opposite to the back E.M.F. plus the internal drop. Now with large traction motors the magnetic circuit contains large masses of iron, the presence of which affects the arc in two ways. In the first place, these masses of iron afford a ready path for eddy currents set up by any alteration in the strength of the field, such eddy currents absorbing the stored energy of the magnetic field when the circuit is broken. In the second place, these eddy currents, by resisting the diminution of the field strength, tend to maintain the back E.M.F. unchanged while the arc is being broken and very greatly reduce the voltage across the switch after the arc is broken. This latter effect is very marked in the case of a shunt motor, in which case the field is kept constant by the shunt winding.

The locomotive controller. Probably the first electric locomotive on a large scale was made for the Baltimore and Ohio Railway.

In the first locomotive for this railway the controller was not very different from the K type of tramcar controller, there being, however, two barrels instead of one, mounted horizontally and rotated simultaneously by a hand wheel.

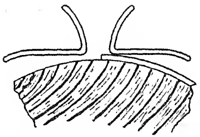


FIG. 184. Type of contact on the Central London Railway locomotive controller.

In the second locomotive this type was abandoned, and all the moving contacts were mounted on a single vertical drum about 40 inches in diameter worked by a lever.

The Central London Railway controller. Following on the lines of the Baltimore and Ohio Railway, the Central London Railway employed similar locomotives with similar controllers.

The method employed in the tramcar controller of making connections by means of the barrel between the different fingers is not here adopted. The method is rather the opening and closing in the proper order of a number of separate switches by means of disconnected contacts on a wooden drum.

The form of the switch is shewn diagrammatically in figure 184; when the gap is bridged by the contact on the barrel the current flows

from one finger to the other. As soon as the gap is opened the arc which is formed is blown along the horns of the fingers away from the points of contact by the magnetic field in which the switch is placed.

Figure 185 gives the diagram of the barrel, omitting, for the sake of simplicity, the reversing barrel and the cut-out switches.

It will be seen that there are two rows of switches at opposite ends of a diameter, the barrel being turned through 160° from off to full speed. There are in all 16 working positions. The following points should be noticed:

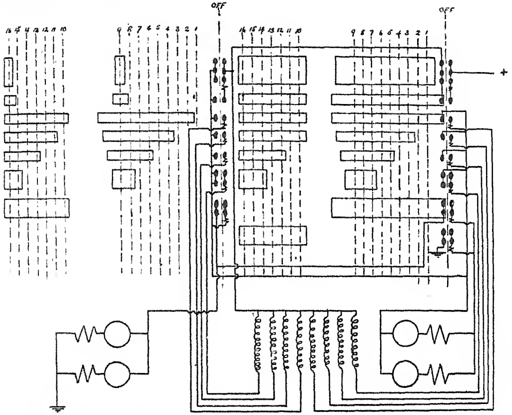


FIG. 185. Diagram of the Central London Railway locomotive controller. (British Thomson-Houston.)

1. The fingers which are of a uniform breadth are grouped together in accordance with the current to be carried; thus the main current requires three fingers in parallel, and those switches which deal with the current for two motors have only two fingers in parallel.

2. The magnetic fields are all produced by the currents through the arcs to be blown out; this ensures that the arcs will always be blown up the horns and not downwards into the barrel.

3. The change from series to parallel is effected by opening the whole circuit and rearranging the connections before closing the circuit again. This is necessary in order to avoid the arc that would be formed on opening the short circuit of two large motors in parallel.

4. The various portions of the resistances are arranged in parallel instead of in series, and, instead of being short circuited step by step, are switched in.

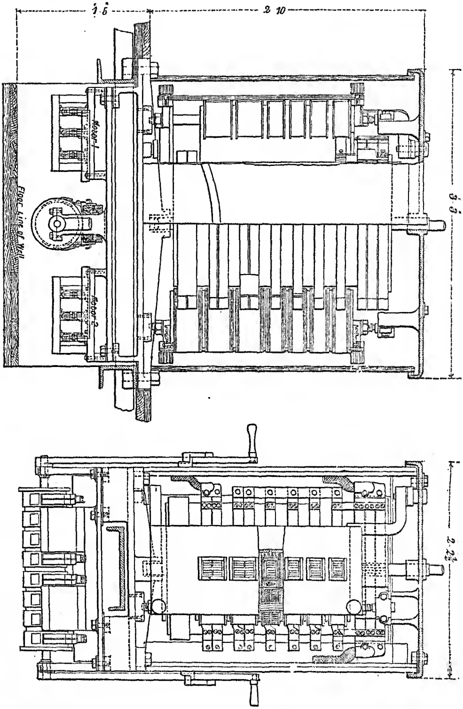


FIG. 186. Elevations of Central London Railway locomotive controller. (British Thomson-Houston.)

Figure 186 shews this controller in elevation and plan. The maximum current is about 1200 amperes, for which three fingers in parallel are provided each about one inch in width.

The main drum is vertical and about 20 inches in diameter; the reversing barrel is arranged horizontally below the main drum and is worked by long vertical levers.

The cut-out switches are also in the base of the controller, and all the usual interlocking is provided for. For the complete diagram of connections see *Electrical Review*, June 29, 1900, p. 1100.

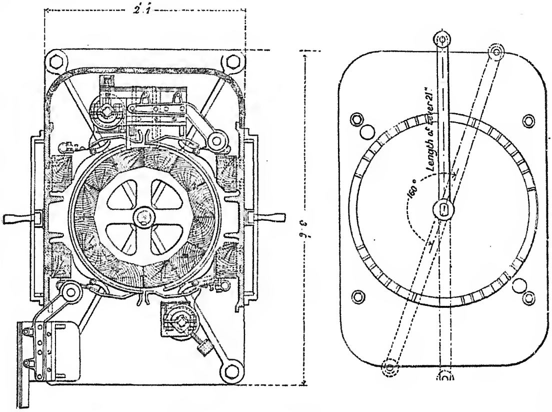


FIG. 186. Plan of Central London Railway locomotive controller.

More recent locomotive controllers. The Central London Railway locomotive is probably about as large as can conveniently be governed by means of a plain hand controller. For currents greater than those involved in this case the apparatus becomes unwieldy and difficult to handle; and in more recent controllers a different system has been adopted.

The N.Y.C. and H.R.R. locomotive. In the express locomotives of the New York Central and Hudson River Railroad the Sprague General-Electric system of control has been installed. This system is described more fully below; but it may be said here that the essence of it, in so far as it concerns the problem of the locomotive, is that the switches are entirely separate from the controller itself and are worked from a distance by means of small currents which are themselves dealt with by a hand controller.

This method has the great advantage that the hand controller is easily managed, and at the same time most complete arrangements can be made for dealing with the heavy currents and destructive arcs.

In the case of the N.Y.C. and H.R.R. locomotive there are four motors and the starting current per motor is approximately 1000 amperes, that is to say the maximum current to be dealt with by the controller is about 4000 amps.

In the start there are three groupings:

1. All four motors in series,
2. Two motors in series, two in parallel,
3. All four motors in parallel.

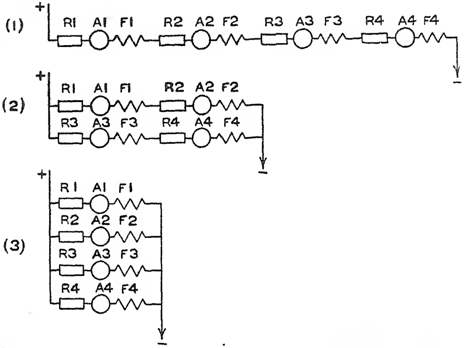


FIG. 187. Diagram of motor circuits, N.Y.C. and H.R.R. locomotive. (General Electric Company.)

There are four sets of resistances, each motor having its own set, the resistances being arranged in the same groupings as the motors, as shewn diagrammatically in figure 187.

The hand or master controller is not unlike a tramcar controller, except that there are two separate barrels for controlling the rheostat and for operating the series paralleling switches. These two barrels are geared together in such a way that the former makes one revolution for each of the three groupings, the operation being identical in each.

Figure 188 gives a general view of the master controller.

The control of motor car trains. So far only the control of trains hauled by electric locomotives has been considered. Entirely

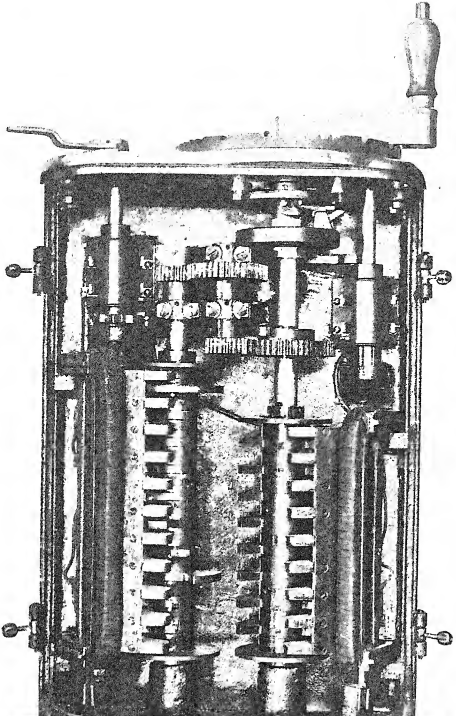


FIG. 188. View of master controller on the N.Y.C. and H.R.R. locomotive. (General Electric Company.)

different circumstances, however, arise if the train is self-propelled. Such trains are composed of motor cars and trailer cars, all being suitable for carrying passengers. The essential difference between such trains and those hauled by electric locomotives is that the motor car trains must be able to travel in either direction without rearrangement of the cars. In other words, wherever the motors and controllers may be situated, they must be arranged so that the train can be driven from either end.

Systems involving two full-sized controllers. The most obvious method of meeting this requirement is to supply at each end of the train a controller capable of operating all the motors on the train. This method has certain disadvantages, being costly and cumbersome. With a six-coach train composed of four trailer cars and a motor car at each end, this system requires a number of heavy cables from end to end of the train, including five sets of flexible electric couplings between the cars.

This method of control has been employed with success on the Waterloo and City Railway, but has not been used extensively.

Messrs Siemens and Halske of Berlin some time ago brought out a system on the same principle, effecting a considerable improvement in respect to the power cables along the train. In cases where only the front and rear cars are equipped with motors, the two sets of motors can be used as the two units necessary for series parallel control. By suitable arrangement of the controller at each end only one power cable is necessary along the train. In practice it is advisable to use two cables, the second being a connection between the current collectors on the front and rear cars. The arrangement as used on the Hoch- und Untergrund Bahn in Berlin, equipped by Messrs Siemens-Schuckert, is shewn diagrammatically in figure 189, in which a and b are the two power cables.

This method has the merit of simplicity and comparative cheapness. The only respect apart from size in which it exceeds a tramcar equipment is in the duplication of the resistances and in the single power cable.

It must be noticed, however, that the direction of rotation of the motors at one end cannot be altered from the other end. That is to say, the system permits of forward running from either end with all the motors; but for running backwards from either end only half the motors are available. This can scarcely be regarded as a drawback; all that is necessary to provide for is that the train can be moved backwards for shunting purposes, and this requirement is fulfilled.

The multiple unit system. The system described above, in which the motors at both ends of a motor car train are controlled from either

end, may be said to be an intermediate stage between locomotive haulage and multiple unit systems. A train may obviously be composed either partially or entirely of motor cars; but any departure from the arrangement of one at each end introduces at once difficulties in the control.

At the same time there are several well-marked advantages in being able to equip as many cars as is desired and also in providing means for controlling such equipments from any point on the train. These advantages may be enumerated as follows:

1. The train may be made up in any order.

2. Any length of train may be employed by including a sufficient number of motor cars.

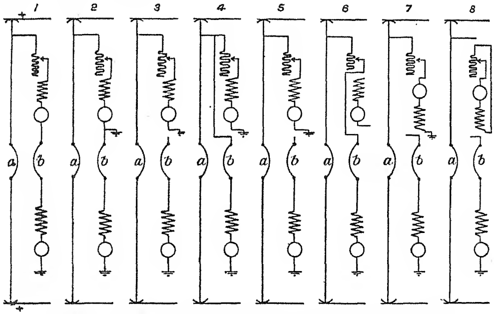


FIG. 189. Diagram shewing motor circuits on the Berlin Hochbahn. (Siemens-Schuckert.)

3. Facility is gained in making and breaking up trains, allowing short trains to be used at times of light traffic.

4. Shunting of locomotives is entirely avoided.

5. The acceleration of the train can be increased, as much as desired within reasonable limits, by equipping a sufficient number of axles.

The last two are perhaps the most important. The possibility of eliminating the locomotive is of great importance as regards large terminal stations; and the possibility of accelerating the whole service is of equal value.

The central idea of the system was brought prominently before the public by Mr F. Sprague in America, and the new method of control

in accordance with his patents was introduced into the scheme for electrifying the South Side Elevated Railway in Chicago, which was carried out in 1898.

The central idea, and means for carrying it into effect. As its name implies, the multiple unit system consists in forming a train of a number of self-contained units and connecting them together by suitable means so as to enable the driver to control the whole train simultaneously.

Each unit will, therefore, consist of a motor car equipped with at least two motors, one series-parallel controller, a set of resistances, and the necessary power cables and current collectors, &c.; further, the controller must be of such a type that it can be completely governed from a distance.

The problem having been stated, it will be obvious at once that there are many ways of solving it. Probably the simplest method, at first sight, would be to employ standard controllers, replacing the handle by a ratchet wheel, the pawl being worked by an electromagnet supplied with current from a small or auxiliary wire running the whole length of the train.

This method, or modifications thereof, entered into almost all the earliest forms of multiple unit controllers. As, however, the method has been more or less superseded, it will be advisable to notice briefly only the various schemes evolved, laying stress on those features which are retained in the more recent types.

Darley and Parshall. As early as 1893 Messrs Darley and Parshall in the United States took out patents for working the controllers on a number of cars simultaneously, by means of a motor attached to each controller and suitable switches for governing all the motors; also for an arrangement whereby a ratchet wheel was mounted on the barrel and was operated by means of a pawl driven by a pneumatic piston.

The Sprague system. This system, the English patents for which were taken out in 1898, also made use of an electric motor (the "pilot" motor) geared to the controller barrel.

The most important feature in this patent is the introduction for the first time of the automatic relay. This was considered at the time of great value, and has been included in many of the systems brought out since.

In its essentials automatic control provides for the maintenance at a predetermined value of the starting current independently of the skill of the driver. In the form patented by Sprague the method consists in the employment of a "throttle" magnet on each motor car

connected in series with one of the main motors and so arranged that the circuit of the pilot motor is opened if the main current exceeds a predetermined value. By this means the progression of the controller barrel is checked on each step until the current has fallen to its minimum starting value.

This application of the automatic method has the advantage of equalising the action of the independent motor cars, each car being self-governing and yet under the driver's control.

Figure 190 gives the essential features of the Sprague system, omitting the reversing barrel and the cut-out switches.

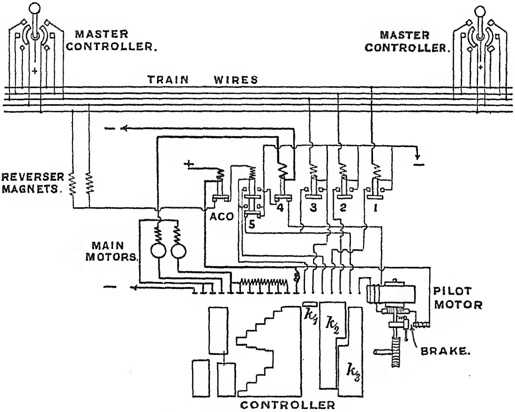


FIG. 190. Diagram of Sprague multiple unit system.

The apparatus consists of a main controller of a standard barrel type extended to accommodate seven smaller contacts for the auxiliary circuits, a pilot motor with two opposite field windings arranged to drive the barrel through worm gearing, a reversing barrel operated by two electromagnets, an automatic cut-out magnet ACO, a "throttle" magnet 4, and four other magnets 1, 2, 3 and 5. Also a master controller for supplying current to these different magnets, which consists of a rotating switch, and three contacts for each direction of running. The electromagnets are connected to switches, the arrangement of which is sufficiently clear from figure 190.

The master controller has six definite positions, three for each direction of running. In the first position, called the "coast" position, the car motors are not operating, but are connected up for forward or reverse running according to the position of the master controller. In the second or "series" position, the motors are connected in series, the regulating resistances being switched out by the progress of the main controller at a speed regulated by the "throttle" magnet. In the third or "parallel" position, the car motors are connected in parallel, the regulating resistances being cut out automatically as before.

By tracing through the connections it will be seen that the following operations are provided for:

1. Turning the reversing barrel to the "forward" or "reverse" position if the main barrel is at "off" (the reverser is replaced in its off position by means of a spring whenever current is cut off from both the reverser magnets).

2. Advancing the main barrel from the "off" position to the full series position at a speed regulated by the throttle magnet 4. This is effected by energising magnet 2, which closes and forms a circuit through the pilot motor and its forward field winding, contact k_2, magnetic switch 2 to —.

3. Returning the main barrel from any parallel position to the full series position at a speed limited only by the motor. This is effected by the contact k_3 and the fingers pressing on it.

4. Advancing the main barrel to the full parallel position at a speed regulated by the throttle. This is effected by closing magnetic switch 1.

5. Returning the main barrel to the "off" position without opening the reverser. This is effected by closing magnetic switch 3.

6. If the current fails the reverser automatically opens, and magnetic switch 5 falls. The reverser cannot be closed again, even when the current is on again, until the main barrel has returned to the "off" position. This provides against an excessive current passing through the motors, which would occur if the supply were re-established after the train had slowed down or come to rest, the main barrel having been left on. This safeguard is effected by the contact piece k_1.

Although this system is now more or less superseded the above operations have been described in detail, because they are at the basis of all multiple unit systems. They are, of course, quite different to the conditions imposed upon a hand controller; but, apart from the automatic feature, they are necessitated owing to the fact that the driver is powerless as soon as the supply fails.

Other systems involving some device for operating standard series parallel controllers will be referred to but briefly.

The Westinghouse electro-pneumatic system. The basis of this system is the use of the compressed air, already provided on the train for other purposes, for operating the various controllers on the different motor cars. The compressed air is controlled by means of electromagnets energised from a small battery on the driver's car through the agency of a master controller.

Figure 191 shews as simply as possible the essential features of this system. It must be understood, of course, that the complete apparatus includes all the necessary safeguards already mentioned in connection with the Sprague system, and several extra safety devices made necessary by the use of compressed air.

In the figure, *mc* represents the master controller containing two pneumatic cylinders c_1 and c_2. In the cylinder c_1, when compressed air is supplied from pipe l_1, the piston moves up against a spring and by so doing opens a switch s in the circuit of the train wire t_1. Simultaneously it engages with the ratchet wheel shewn in the figure and rotates it one step. Mounted on the same shaft with the ratchet wheel are an index plate i and a spur wheel. The latter engages with a rack attached to the piston of the cylinder c_2. The master controller also contains the necessary switch for connecting the positive pole of a small battery to the point marked +.

The main controller barrel is driven through gearing by the shaft z. On this shaft are mounted a large ratchet wheel w_1 with a number of teeth, and a smaller ratchet wheel w_2 with three teeth spaced as shewn, and a spur wheel w_3 engaging with a rack r. The two ratchet wheels are driven by pawls from the piston p_1 and the rack by piston p_2. Compressed air is admitted to the cylinders k_1 and k_2 by the electrically operated valves v_1 and v_2.

The operation is as follows: The driver by means of the master controller connects the + pole of the small battery to one of the magnets which operate the reverser (not shewn). He next connects it to the train wire t_1 through the switch s, and also to the train wire t_2. This energises the two magnet operating valves v_1 and v_2 which are so arranged that valve v_1 admits pressure to the cylinder k_1 and valve v_2 connects cylinder k_2 to atmosphere. The piston p_1 moves forward in consequence of the pressure, and one of the pawls engaging with wheel w_2 causes the main controller to move a large step. At the end of the stroke the pressure is admitted through the throttle valve TV to pipe l_1 and cylinder c_1. The admission of air to c_1 is through a small hole the size of which can be regulated to obtain the desired speed of switching on.

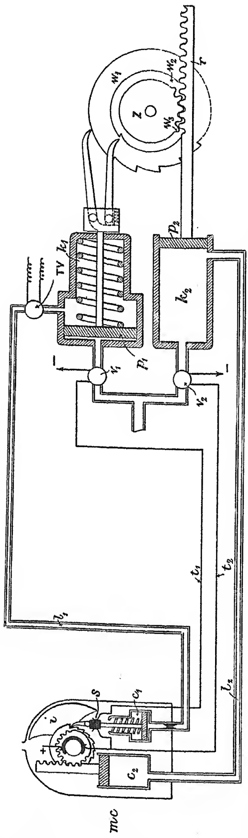


FIG. 191. Diagram of Westinghouse electro-pneumatic control system using barrel controllers.

The piston in this regulating cylinder moves up, and in so doing opens switch s, turns the index plate through one step, and also moves the piston in the cylinder c_2 downward. The opening of the switch s de-energises the magnet of valve v_1, which therefore cuts off the pressure, and opens cylinder k_1 to the atmosphere. The piston p_1 is pushed back by the spring ready for the next stroke on the ratchet wheel w_1, and simultaneously the regulating piston in the master controller falls and closes switch s. This process is repeated until either the full series or the full parallel position is reached.

Switching off is effected by cutting off the battery from the valves v_1 and v_2. This admits pressure to k_2 and turns the main controller to the off position by means of the rack r. At the end of the stroke air passes through pipe l_2 to cylinder k_2 and turns the index plate back to the start.

It will be seen that the automatic regulation is provided for partly by the throttling of the air supply to the regulating cylinder c_1; beyond this the throttle valve TV checks the action if the motor current has exceeded the proper amount.

The Siemens-Schuckert electro-pneumatic system. Messrs Siemens-Schuckert have devised a somewhat similar system, in which the main controller on each motor car is turned round by a pneumatic cylinder, the air supply being controlled by electro-pneumatic valves. In this system, however, there is no ratchet, a steady movement of the piston producing a uniform rotation of the controller barrel. The rate of motion is governed automatically by means of an oil dash pot, consisting of a piston working in an oil-filled cylinder, the two pistons being mechanically connected so that they move at the same speed. The governing is effected by the regulation of a small orifice through which the oil escapes; the size of this orifice and consequently the rate at which the oil can escape is controlled by a throttle magnet in which the main current flows.

This system has been installed on some of the trains running on the Hoch- und Untergrund Bahn in Berlin.

The unit switch systems. All the multiple unit systems described so far have been based upon the use of standard series parallel controllers of the tramcar or barrel type. This basis has obvious advantages, being simply an adaptation of well known and well tried apparatus to conditions not very different from those which gave rise to it. On the other hand it has its own limitations. If a train is to be composed of motor and trailer cars it is obviously better to concentrate the equipments as much as possible. Thus it would be preferable to put two 200 H.P. motors on each of two cars out of a total of eight than to put two 50 H.P. motors on each car. Now a

barrel type controller for two 200 H.P. motors is necessarily somewhat bulky. Considerations of space and the desirability of making ample provision for the breaking of arcs (especially those which occur with powerful motors), and the paramount necessity of guarding against risk of fire, have led to the adoption of systems which enable the controlling apparatus to be placed under the car, and which facilitates the isolation of the arcs which occur in practical operation.

The unit switch systems are based upon the separation of the constituent parts of a controller. As has already been seen in the case of the Central London Railway locomotive, a controller is but an aggregation of a number of switches. There is no reason, beyond convenience of handling and cheapness, why each switch should not be treated as a distinct unit; and this separation into distinct units is the

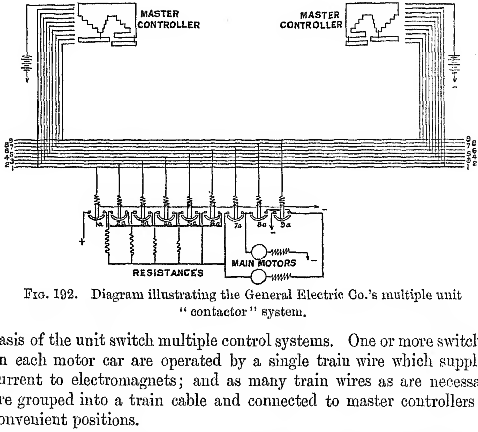


Fig. 192. Diagram illustrating the General Electric Co.'s multiple unit "contactor" system.

basis of the unit switch multiple control systems. One or more switches on each motor car are operated by a single train wire which supplies current to electromagnets; and as many train wires as are necessary are grouped into a train cable and connected to master controllers in convenient positions.

This system has also the advantage of quick and definite action, which is not possessed in the same way by the systems already described.

The Sprague-General Electric Co.'s "Type M" control. In 1898, about the same time as the Sprague multiple unit control was brought forward, the General Electric Company of America introduced their unit switch or "contactor" system. In its simplest form it is shewn in figure 192, in which 1, 2, 3 ... 9 are the train lines

running from end to end of the train. On each motor car are nine magnets which serve to close the various contactors $1a$, $2a$, $3a$, etc. Connected to these train lines are the master controllers of which two are shewn. A small battery is installed to supply current to the train wires. Contactor $1a$ connects the + line to the resistances, $2a$, $3a$, $4a$, $5a$ and $6a$ regulate the resistances, $8a$ when closed puts the motors in series, and $7a$ and $9a$ connect them in parallel. The master controllers are similar to tramcar controllers and are operated in precisely the same way. The working of the system can be seen quite clearly from the figure.

In actual practice the apparatus is of course not quite so simple. In the first place it is generally considered better to eliminate the battery and to supply current to the contactor magnets from the line. Now, a small magnet wound for 500 volts requires very fine wire and is expensive, and liable to break down when its circuit is opened. To avoid this the auxiliary circuits are so arranged that several magnets are connected in series. By this means the voltage on each magnet may be reduced to say 100 volts. Naturally, while switching on, the number of magnets that can be arranged in series must vary; and, in order that the magnetising current may be kept substantially constant, substitutional resistances are employed.

Figure 193 gives the diagram of the circuits for this system. In this figure the contactors are numbered in large numerals from 1 to 13, and the various wires in the control circuits in small numerals. The master controller has two barrels, a main and a reversing barrel. The latter is shewn at the top of the figure; immediately below it is the apparatus connected to the dead man's handle (see below) which is arranged to cut off all current from the control circuits if the driver lifts his hand from the controller handle. The lower part of the master controller contains the main barrel with its magnetic blow-out coil. Current is supplied to the controller through a "control circuit switch" and fuse. The control circuits for each car go through a "cut-out switch" which can isolate any car without interfering with other cars. For the proper regulation of the control currents a control circuit rheostat is supplied. The main reverser is designed on the usual lines, operated by two magnets; it also contains auxiliary contacts with magnetic blow-outs, which are so arranged that unless the main reverser is in the proper position as required by the master controller, current cannot pass to the coils of the various contactors.

For purposes of electrical interlocking three contactors, 2, 11 and 12, are provided with auxiliary contacts, such that when any one of the contactors is closed the circuit through the auxiliary contacts of that contactor is opened. These extra contacts on switch 2 prevent the

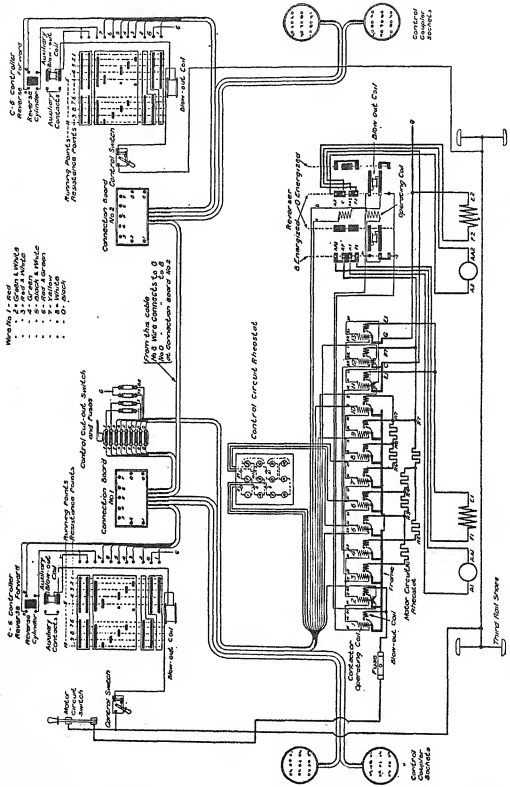


FIG. 193. Diagram of connections of the Sprague-General Electric "Type M" multiple control.

main reverser from being put over unless contactor 2 is open. The extra contacts on switches 11 and 12 serve to provide against the possibility of these two switches, which are the switches for the series and parallel grouping respectively, being closed simultaneously; if this were not guarded against a "dead" short circuit might be the result.

For the purpose of tracing out the working of the control the following symbols may be used:

The numeral 1 for wire 1.

A numeral with a circle round it, thus ①, for the operating coil of contactor 1.

A numeral followed by the letter *a*, thus 1*a*, for the auxiliary contacts on contactor 1.

The letter r with suffix, thus r_1, for the corresponding unit of the control rheostat.

The circuits may be traced out as follows:

Close the control circuit switch and put the reversing handle to "forward" and the main handle to position 1; current flows from the third rail shoe on the left through the control circuit switch and fuse and the dead man's handle contacts to the second finger from the top; from this point it flows through the reversing barrel to wire 8. The circuit is then as follows: 8, operating coil of reverser, 81, 2*a*, fuse, ground; this coil pulls over the reverser and the circuit is then 8, operating coil of reverser, 15, ①, 14, ②, 13, ③, 12, ⑪, 12*a*, 1, fuse, master controller, ground. This connects the main motors in series with all resistance in.

Position of master controller	Control circuits	Contactors closed
1.	8, operating coil of reverser, 15, ①, 14, ②, 13, ③, 12, ⑪, 12*a*, 1, fuse, master controller, ground.	1, 2, 3, 11
2.	8, coil, 15, ①, 14, ②, 13, ③, 12, ⑪, 12*a*, 1, ground, and 3, r_{12}, r_9, r_6, r_5, r_8, r_{11}, 31, ⑤, 32, fuse, ground.	1, 2, 3, 11, 5
3.	8, coil, 15, ①, 14, ②, 13, ③, 12, ⑪, 12*a*, 1, ground, and 4, r_{10}, r_7, r_4, r_1, 41, ⑥, 31, ⑤, 32, fuse, ground	1, 2, 3, 11, 6, 5
	and so on.	
5.	8, coil, 15, ①, 14, ②, 13, ③, 12, ⑪, 12*a*, 1, ground, and 7, ⑩, 71, ⑨, 6, ⑧, 51, ⑦, 41, ⑥, 31, ⑤, 32, fuse, ground	1, 2, 3, 11, 10, 9, 8, 7, 6, 5

This connects the motors in series without resistance. In the transition from position 5 to position 6, resistances are reinserted, and then all circuits are opened. On reaching position 6 fresh circuits are made thus:

6.	8, coil, 15, ①, 14, ②, 13, ④, 23, ⑫, 22, ⑬, 21, 11*a*, 2, master controller, ground.	1, 2, 4, 12, 13

The motors are now connected in parallel with resistance in circuit, and this resistance is cut out step by step as before.

Introduction of automatic feature. In the system described above the entire control remains in the hands of the driver, and no attempt is made to introduce any throttle switches. In 1903 when the Rapid Transit Subway in New York was electrically equipped, the contract for the multiple unit control was let to the General Electric Company. In this system automatic regulation was first introduced into the "type M" control; and the introduction consisted of an addition to the master controller. The driver's handle was connected to the barrel through a spring, and the motion of the barrel was regulated by means of a throttle magnet. This arrangement enabled the driver to put his handle to any position with the assurance that the barrel would follow at the correct rate. This type of control was supplied to the North Eastern Railway for the lines near Newcastle by the British Thomson-Houston Company, and has been in constant operation since the opening of the new system in March 1904.

Sprague-General Electric Automatic Relay System. In 1902 Mr F. Sprague patented various methods of automatic control involving the use of contactors. These methods are based upon the combination of a throttle magnet switch with auxiliary contacts on the main contactor switches, the connections being so arranged that the current operating a contactor magnet passes through the auxiliary contacts of the contactor previously closed and through the throttle switch. Thus until the motor current becomes too great, the contactors close automatically one after the other. A system involving this principle was installed on the Boston Elevated Railway in 1904 by the General Electric Company. The method of operating the contactors with their auxiliary contacts is shewn in figure 194. In this figure accelerating wire No. 1 serves to supply current from the master controller for the process of switching on; wire No. 2 also supplies current from the master controller for the purpose of holding up the contactors as they are closed by the other circuit. The arrangement is shewn clearly in the figure and the method of operation is as follows:—Assuming

that the master controller is turned so that accelerating wire No. 1 and wire No. 2 are both made alive, and that initially all the contactors are open, *i.e.* in the position shewn in figure 194, and the throttle relay down: current passes from wire No. 1, through the

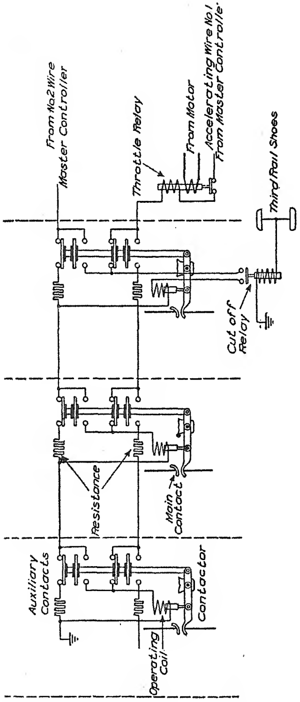


FIG. 194. Diagram illustrating the principle of the Sprague-General Electric Automatic Relay System of control.

throttle relay, through the auxiliary contacts on the first contactor, through the cut-off relay (which is closed whenever the collector shoe is alive) and passes to the electromagnet of contactor 1 and thence to the upper of the two horizontal wires, through the auxiliary contacts of the

other contactors and the resistances to earth. As soon as the current flows through the electromagnet the contactor closes, and in so doing lowers all the auxiliary contact plates connected thereto. At the same time the main motor current flows through the throttle relay and opens the circuit of wire No. 1. The current in this circuit is, therefore, cut off; but the contactor 1 is held closed by current supplied from wire No. 2 through the auxiliary contacts attached to contactor 1. In this condition the control connections are such that as soon as the main current falls to a predetermined value and the throttle relay closes again, the same operation takes place with contactor 2. In this way the switching on progresses automatically at a predetermined rate. To prevent chattering of a contactor when the operating coil is first energised, the throttle relay has a lost motion so that it does not close instantly but allows the contactor to close before breaking the operating circuit.

It will be noted that the throttle relay has two windings, one in series with the motors and the other in series with the operating circuit. This point will be referred to later when the constructional details are discussed.

The wiring diagram for the complete equipment of a car is given in figure 195, which shews the control system very clearly. A later diagram prepared by the General Electric Co. contains a few slight modifications, chiefly in the order of cutting out the resistances. The latter, however, is more complicated, and as it is almost impossible to trace out the successive operation of the various contactors without the aid of an elaborate description, it has not been inserted here.

As will be seen there are 6 train wires; wire 1 provides for automatic acceleration; wires 2 and 3 for holding up the contactors in the series and the parallel grouping; wires 4 and 5 for operating the reverser. Wire 6 is connected to a special switch in the driver's compartment, which, when closed, supplies current to a magnet on each motor car which can disconnect all the auxiliary circuits from the master controller; this enables the driver to cut off power from the whole train in case of emergency.

There are also in the driver's compartment a main switch, a master controller switch, a connection box and the throttle relay.

The master controller has only a single barrel with 10 fingers. There are 6 positions of this barrel besides the "off" position, viz. 2 forward series, 2 forward parallel and 2 reverse series. This arrangement eliminates the separate reversing barrel with the usual interlocking gear.

The rest of the equipment includes a reverser of the same type as that installed with the Type M control, also 15 contactors, the motors

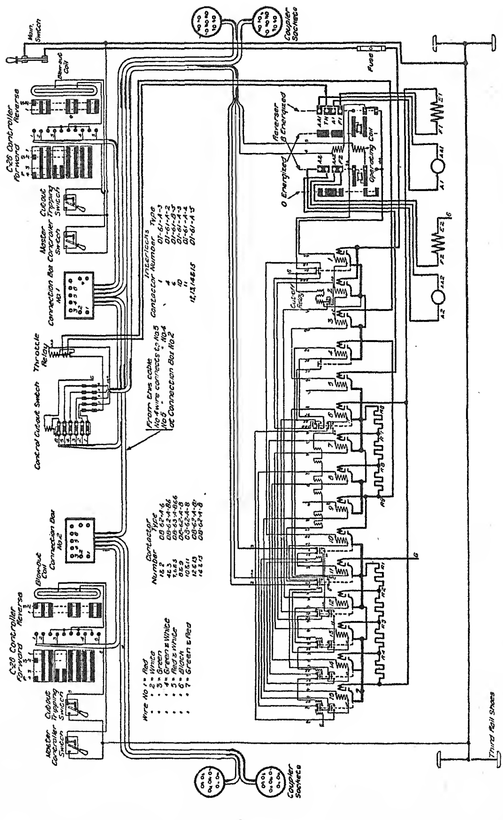


Fig. 195. Wiring diagram for motor coach equipped with the Sprague-General Electric Automatic Relay System of control.

and resistances and finally a "cut-off relay." This latter is provided so as to open the control circuits on any car which is passing over a "dead" section, and to put back the controller to its first position, viz. motors in series all resistance in. As soon as the dead section is passed the cut-out relay closes and the controller progresses automatically to the position it previously occupied. This is designed to prevent flashing across of the motors.

The general method of operation has already been referred to. The actual proceeding is as follows:—After closing the main switches on all the motor cars and the master controller switch in the driver's compartment, the master controller is turned to the first forward position. Current flows from the + line to train wires 4 and 2. The former puts the reversers to their forward positions, and then passes to contactor 1, to 2, to 3, to 5, to – line or earth. Current also flows along train wire 2 through 10 (the series contactor) and through the auxiliary resistances to earth.

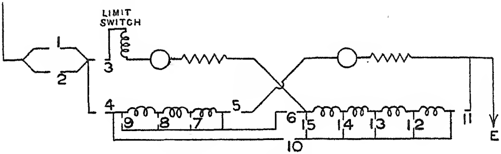


FIG. 196. Diagram of motor connections on the Bridge System of control.

With the master controller in the second forward position current flows along train wire 1, through various auxiliary contacts and through the cut-off relay, through 12 and the auxiliary resistances to earth. When the motor current permits the throttle to close again, the current flows through 13 and 7 and then 14 and 8, and then 15 and 9, and finally 6. The closing of 6 cuts off current from 10, and from all the resistance contactors. The motors are at this stage in full series.

In position 3 of the master controller, current is cut off from train wire 1, and passes to train wire 3. This closes 4 and 11, which cuts off current from 6. On position 4 current flows to train wire 1 and the resistance contactors close automatically until the motors are in parallel with all resistance cut out.

The diagram of connections in the motor circuits is shewn in figure 196.

The Bridge system. As will be evident from figure 196 the method of switching from the series to the parallel grouping is novel.

The chief feature of this system called the Bridge system is that the circuit is not opened during the change from series to parallel grouping. The current in each of the two motors remains practically constant, and consequently there is no remission of the tractive force and no jerk on the train. A further advantage is that as the change from series to parallel does not involve opening any circuit, no arcs are formed at this stage in the process.

The Westinghouse automatic contactor system. The Westinghouse Company in the United States have introduced a somewhat similar system in which the various contactors are operated by pneumatic cylinders controlled by electromagnetic valves. These contactors have auxiliary contacts whereby progressive switching on is effected automatically. The method of automatic operation is very similar

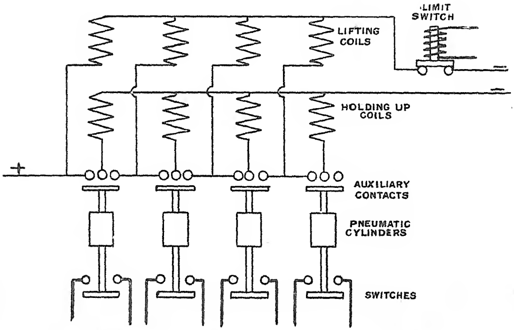


FIG. 197. Diagram illustrating the automatic feature of the Westinghouse "unit switch" control system.

to that in the Sprague General Electric System; the arrangement is somewhat different as the source of current from which the valve magnets are supplied is a 15 volt storage battery, and consequently there is no necessity to connect a number of magnets in series. The principle of the arrangement is shewn diagrammatically in figure 197, from which the method of working can be clearly seen.

The Bridge system of working can be employed with this apparatus as well as with other types, as may be seen from the diagram in figure 198. This figure gives the complete wiring diagram for a motor coach equipped with two 200 H.P. direct current railway motors,

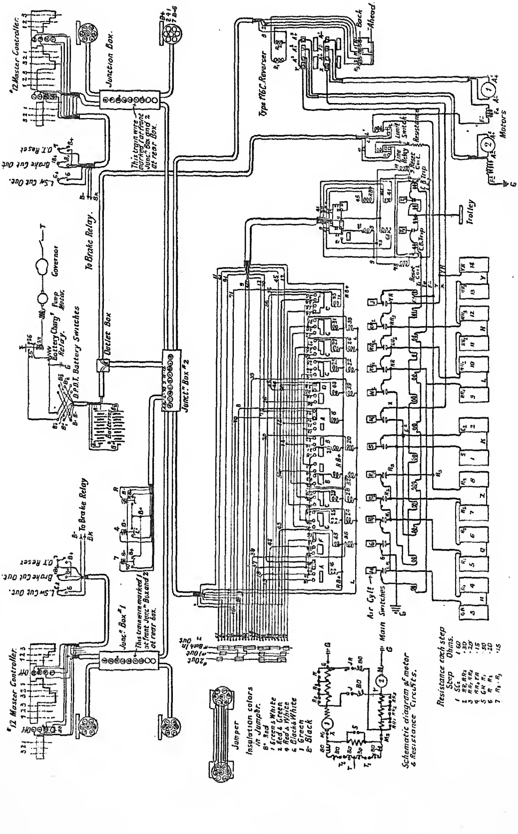


FIG. 198. Diagram of connections for the Westinghouse Electro-pneumatic "unit switch" control system.

and apparatus for controlling a train of such coaches on the electro-pneumatic unit switch system.

Before following through the control circuits, a few words of explanation are necessary with regard to the various parts of the apparatus and their functions. Two master controllers are shewn one in each top corner of the diagram; each contains four contact pieces electrically connected, forming a barrel which is rotated by the handle, in one direction for "forward," in the other for "reverse" running. At opposite ends of a diameter are two rows of contact fingers, marked thus:

1	6A
2	1B+
1B+	4
BK	7

This drum tends to return to its central or "off" position under the action of a spring. In this position not only is current cut off from the control circuits, but in addition the air brakes are put on through an emergency brake magnet valve, unless the brake cut-out switch has been opened previously. In normal operation the driver switches off by returning the master controller to the "semi-off" position, between the first and the "off" positions; if he lets go the handle it returns to the "off" position and puts the emergency brakes on. A view of this master controller is shewn below in figure 201.

In connection with each controller there are three small switches marked respectively L. Sw. cut-out, Brake cut-out, and O.T. reset. Besides these switches there are on each motor coach:—three control circuit relays, two 15 volt batteries, switches and other accessories in connection therewith, the usual junction boxes and couplers, a switch with four positions for cutting out either or both motors, a unit switch group of 12 switches, a pair of switches forming the line switch, a line relay, a limit switch and a reverser.

The Line switch cut-out is a small knife switch, and when opened prevents any of the line switches on the train being closed, although the switch groups may be operated; this is convenient for testing the control and may be useful as an emergency cut-out.

The Brake cut-out is a similar switch which, when open, cuts off current from the master controller.

The overload trip reset switch is normally held open by means of a spring; when this switch is closed in the "off" or "semi-off" position any overload trip may be reset.

The three control circuit relays are shewn in the diagram close to the master controller; two of them are operated direct from the train wires and the third from the train wires through the reverser on the same car. These three relays enable almost the whole control on each car to be effected from the storage batteries on that car, and not from the batteries on the front car. The switch group contains 12 electro-pneumatic "unit" switches, each of which is fitted with auxiliary contacts, the relative positions of the fixed and moveable auxiliary contacts as shewn in the diagram corresponding to the open positions of all the unit switches. Each switch is controlled by a valve magnet which is wound with two coils (in most cases), the lower coil closing the switch and the upper holding it closed.

The line switch is a pair of similar "unit" switches which correspond to the switches marked T_1 and T_2 in the schematic diagram of connections. It is fitted with auxiliary contacts, closing and holding-up magnet coils, and blow-out magnet coils. It has a special feature in that any excessive current in the blow-out coils of either switch trips a small switch which opens the connection between control wires 11 and 9, the latter being connected to the negative pole of the batteries. Thus any excessive current through either motor causes the opening of all the unit switches on that car.

The line relay serves to prevent any switches being closed when there is no voltage on the third rail, and puts back the main control to its starting point whenever the car runs on to a dead section. The limit switch regulates the rate at which the switching on progresses, and opens the circuit of the accelerating wire L whenever the current in one of the motors (No. 1) exceeds a predetermined value. The reverser is of the usual type for two motors with auxiliary interlocking contacts as shewn.

With these preliminary explanations the operations of the control circuits on a single car can be traced out as follows:

The line switch cut-out and the brake cut-out are both closed and the master controller turned to its first forward position. Current flows from the positive pole of the battery B +, through the brake cut-out to 1 B + and thence to the master controller, and to train wire 1, and also through the line switch cut-out to train wire 6. These two train wires being made alive on any one motor coach produce the following results, denoting as before wires by numerals and letters, auxiliary contacts by the letter *a* and magnet coils by a circle round the letters. Current flows as above to the two train wires and to the following circuits:

1, R_1 (assuming reverser previously arranged for reverse running), coil, R, control relay coil, B −: this pulls over the reverser and closes the control relay, and the circuits are then rearranged thus:

1, R, B – ;

also B +, control relay, RB +, M_1, B, B – ;

also B +, control relay, RB +, JR, 16, G*a*, 15, 14, J*a*, 13, M_1a, 12, line relay, 11, CB trip, 10, CB trip, 9, B – ;

also 6, 61, T, 11, CB trip, 10, CB trip, 9, B –.

As a result, the unit switches T_1, M_1 and JR are closed, and the motors are connected in series with all resistance in.

Proceeding to the second position of the master controller, train wire 4 is made alive, and closes all the corresponding control circuit relays on the motor coaches. This connects B + to L′, and thence through the limit switch to the accelerating wire L. The following operations then take place at a rate governed by the limit switch:

L, S, 20, 19, JR*a*, 18, 17, 11, trip, 10, trip, 9, B –.

As a result S closes and is held up by

RB +, S, 21, S*a*, 18, 17 and so on to B –.

Next L, RR_1, 22, S*a*, 14, J*a*, 13, M_1a, 12 etc. to B –.

As a result RR_1 closes and is held up by

RB +, RR_1, 23, RR_1a, 22, S*a*, 14 etc. to B –.

In this way the process of switching on progresses automatically as controlled by the limit switch, and with care the whole cycle of operations up to full series, and, if the master controller is turned to the third position, up to full parallel, can be traced out. If this be done it will be seen that the transition from series to parallel is effected on the Bridge system. An examination of the schematic diagram will also shew that it is possible by leaving open T_1 and T_2, reversing the motors and closing M_1 and M_2, to cause the motors to generate in a local circuit, thus providing a rheostatic brake. To effect this, the line switch cut-out is opened and the master controller turned to the third position for reverse running. In doing so, however, it would have to pass the "off" position, and would therefore momentarily put on the emergency brake in passing.

General remarks on the two automatic relay systems. It is of considerable interest to compare the two automatic relay systems described above. Apart from the different arrangement of the switching as seen in the schematic diagrams, the chief cause of divergence is the use of a low voltage battery in one case, and the line voltage in the other case, for the supply of current to the control circuits. This distinction gives rise to most of the differences between the systems. Perhaps the most important point is that in the Sprague-General Electric system all the current for the control passes along the train wires from the master controller, whereas in the Westinghouse system

most of the control on each car is effected by the batteries on that car, through the agency of the control circuit relays, which are themselves operated from the master controller through the train lines. It is important to note, however, that in the latter case the line switches are governed directly from the master controller without the interposition of any relays. This point of difference is important, as the use of intermediate relays adds an extra link in the chain of the remote control; thus the comparison between the two systems in this respect is as follows:

Sprague-General Electric: line—master contoller—train wire—magnet—switch.

Westinghouse*: battery—master controller—train wire—relay—valve magnet—valve—switch.

This indirectness is a disadvantage incidental to the latter system, although it may be compensated for by concurrent advantages. The use of the low voltage, however, may cause trouble owing to bad contact in the couplers between the cars, and the use of compressed air may give trouble from the presence of grit in the valves. On the other hand, the use of high voltage may create difficulties and interfere with the proper working due to surface leakage across from one point to another in the coupler, and also due to sparking and leakage at the "interlocks" or auxiliary contacts.

Apart from this essential difference there are divergencies of detail, such as the arrangement of the line switches with their trips and reset coils, and of the switch S in the case of the Westinghouse system as compared with the two contactors 1 and 2 in the Sprague-General Electric system, and various other slight differences which will be obvious on inspection.

Dick Kerr unit switch system. Recently a novel system of train control with unit switches has been devised by Messrs Dick Kerr and Co., and put into operation on the Liverpool to Southport Branch of the Lancashire and Yorkshire Railway. The distinguishing feature of this system is that the current which is utilised for the operation of the contactors is not independent of the currents in the motors as in the other systems already described. On the contrary, the motor current itself is employed for this purpose.

The principle of the system can be best gathered from the diagram in figure 199, and the actual connections are shewn in figure 200. In the first of these figures T represents the third rail collector shoe, MM the two driving motors with their field windings and regulating

* It must be remarked that these control relays are not used in some other forms of the Westinghouse electro-pneumatic unit-switch control.

resistances, *cc* and CC switches for completing the motor circuit, and W a throw-over switch which in one position connects the end of the motor circuit to earth, and in the other to the operating coils of the contactors. The method of control is as follows:

The switches *cc* are closed, and W turned so that the motor current may pass to the contactors and thence to earth at E_1. This current energises the contactor magnets and closes the switches CC, which then take the place of the temporary switches *cc*. At this stage the motors are in series with all resistance in circuit. As the speed of the train rises resistance is cut out by diverting the motor current through other contactor coils to earth. Similarly the motors can be grouped in parallel and the resistances cut out as before.

The method of carrying out this principle in practice can be seen from figure 200. The master controller contains three barrels (1) the switch barrel, (2) the reversing barrel, and (3) the contactor barrel. The switch barrel consists of several contact rings and segments for

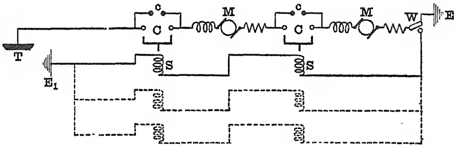


FIG. 199. Diagram illustrating the principle of Dick Kerr & Co.'s multiple unit system of train control.

closing the motor circuit before the contactors are closed, and includes the "earthing sector" and the "solenoid sector" which are indicated by W in figure 199. The reversing barrel is similar to an ordinary reversing switch, and is provided with contacts, corresponding to *cc*, figure 199, which are temporary substitutes for the main reversing contactors. The contactor barrel provides for the connection of the motor circuit to the various contactor magnet coils.

The switch barrel and the contactor barrel are turned by the same handle; but the former can be moved through a certain angle before the latter begins to move, as shewn in the figure. In the base of the controller a small magnet is situated which, when its coil is energised, locks the contactor barrel. This magnet is connected as a shunt across the series switch contactor number 1; if therefore this contactor does not close for any reason the motor current flows through the locking magnet; if the series contactor operates properly this magnet is short circuited and the contactor barrel is set free.

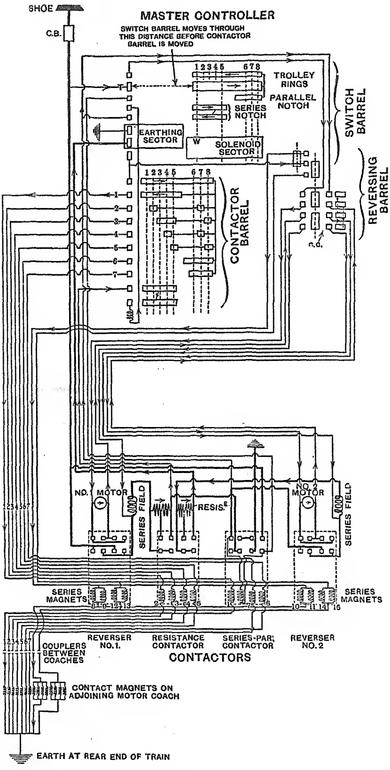


FIG. 200. Diagram of connections of Dick Kerr & Co.'s multiple unit control of two motors. (Motor cut-out switches not shewn.)

Each motor coach contains 16 contactors in four groups. Two of these groups serve as reversers for the two motors, the third group controls the resistances, and the fourth the series parallel grouping of the motors.

The operation is as follows: the reversing barrel is turned to "forward" or "backward" and the main handle turns the switch barrel and then the contactor barrel to "position 1." The current then flows as indicated in the figure by the arrow heads, thus: third rail shoe, circuit breaker CB, trolley ring, reversing barrel, armature No. 1, reversing barrel, Field No. 1, resistances, through the two lowest rings on the contactor barrel, locking magnet, series notch on switch barrel, reversing barrel, armature No. 2, reversing barrel, Field No. 2, resistances, solenoid sector; the current then splits up, part going to the upper contacts on the reversing barrel, and thence to the reversing contactors on all the coaches, and part going to the contactor barrel, and thence to the series switches contactor No. 1; both currents go to earth at the far end of the train. In consequence, the reverser contactors close and take the current of the motors instead of the contacts *cc*, and the motors are connected in series by the contactor No. 1, which thus short-circuits the locking magnet, and permits the contactor barrel to be moved forward. In the other series positions, contactors 2, 3, 4 and 5 are closed, and thereby cut out the resistance in steps. On leaving "position 5" the resistance is inserted again and one motor circuit broken after the other has been shunted. On "position 6" the two motors are in parallel and the current flows thus: shoe, CB, trolley ring, parallel notch, magnet of the contactor between contactors 1 and 7, reversing barrel, armature No. 2, reversing barrel, Field No. 2, resistances, solenoid sector, and thence, as before, the current passes to the contactor barrel and to the reversing barrel, operating the parallel contactors 6 and 7, and the reversing contactors 8, 9, 10 and 11. The motors are thus connected in parallel and in positions 7 and 8 the resistance is cut out.

It will thus be seen that the current utilised for operating the contactors is that which flows in one motor only, whether the motors be in series or in parallel. Further this current splits up into at least 5, and sometimes 6 and 7 parallel paths; the magnet coils therefore do not carry so much current as to make them unwieldy or difficult to wind. On the other hand, the current which passes along the train for operating the reversing contactors amounts to about two-thirds of the current of one motor, and therefore needs a substantial connection in the couplings. As the magnets of the contactors are wound with only a few turns, their inductance is low, and the

opening of the local circuits in which they are connected does not give rise to any appreciable arcs. Moreover, in switching off, the switching barrel is turned backwards and short-circuits all of the contactors by means of the earthing sector before the contactor barrel is moved. There is thus no need for any magnetic blow-out arrangements in the master controller. A further advantage in this system is that all the contactor magnets and all the couplings are at earth potential.

Provision is of course made for operating the train from either end by putting to earth all the train wires that go between the master controller and the contactors. This has been omitted from the drawing for the sake of clearness.

Constructional details of the unit switch systems. So far the unit switch systems have been considered only from what may be called a diagrammatic standpoint. The constructional details of the apparatus whereby the various operations are performed are of great interest.

The master controllers in their construction have not produced any wide departure from standard practice; in fact they are more like tramcar controllers than would be expected. It might be thought that as the auxiliary currents are quite small there would be no necessity for magnetic blow-outs in the master controllers. When the currents in the train wires are derived from a small storage battery and operate magnetic valves as in the case of the Westinghouse systems this is true, and in these systems the master controllers are quite simple. Figure 201 shews that employed with the low voltage Westinghouse system described on page 291.

In the magnetic contactor systems of the General Electric Company, the voltage on the train wires is the line voltage, and the currents required to operate several cars in parallel are not extremely small. Moreover the inductance of the powerful magnets employed is very considerable. For these reasons an arc shield with magnetic blow-out is provided.

Contactors. The chief interest in the apparatus of the unit switch systems lies in the design of the contactors. Considering first the purely magnetic contactors it may be said that these consist of the following parts:

(*a*) The magnet.

(*b*) The switch or contacts.

(*c*) The provision for dissipating the arcs.

(*d*) The framework for combining the above-mentioned parts.

Figure 202 shews the construction of the contactor made by the General Electric Company of America. The magnet is seen most clearly in the side elevation, and consists of a fixed iron core A held by the top plate B. This top plate is rigidly connected to the bottom plate C by two stout wrought iron posts D, D screwed into the upper and bolted to the lower plate. The magnetic circuit is completed by

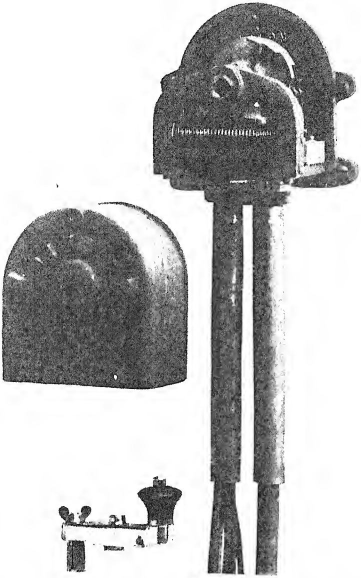


FIG. 201. View of master controller for use with the Westinghouse Electro-pneumatic "unit switch" control system.

the plunger or armature E which is attracted to the core A by the magnetic pull. The plunger slides in a brass tube round which the coils are placed. There are two coils F, one above the other, and as the gap in the magnet is situated at the centre, both coils can be removed, one after the other, by simply withdrawing the plunger. The core is $1\frac{1}{2}$ inches in diameter, and the plunger slightly less, and

hence the effective area is about 1·6 square inches. With an induction across the gap of say 10000, the pull on the plunger would be about 100 lbs., and with 14000 induction about 200 lbs.

The switch itself consists of a fixed contact G and a moveable contact H carried by the lever arm K. The lower contact is actuated from the plunger by means of a compound lever composed of the

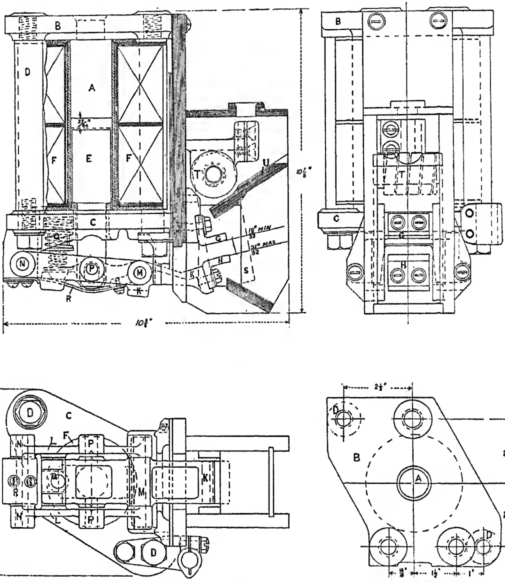


FIG. 202. Magnetic contactor. (Sprague-General Electric "Type M" control.)

two parts K and L. These two parts are hinged together at M, and the lever L is hinged at the fixed pivot N and to the plunger at P. The end of the lever arm K is pressed downwards by a powerful helical spring Q. The action of this compound lever is as follows: when the plunger is drawn up it carries with it the whole lever and the contact H; as soon as the two contacts meet further motion of that end of the lever K is

arrested, but the other end continues to rise compressing the spring, and pivoting about M. This motion provides that after contact is first made at the tips of the contact pieces, these two pieces roll on each other with a small amount of sliding so that the final contact is made at the inner edges. In this way when the switch opens and the motion is reversed, the final break takes place at the tip, whereas the working contact is at the inner edge, and hence the burning due to the arc does not interfere with the proper working of the switch. The sliding motion also helps to improve matters by rubbing off any beads of copper that may be formed by the arc. The levers are made of cast brass or gun-metal and the contact pieces which are renewable are of copper $\frac{1}{4}$ inch thick and $1\frac{1}{2}$ inches wide. Current is conveyed to the lower lever by means of a flexible connection R.

The provision for dissipating the arc is clearly seen in the figure; it consists of a magnetic field set up between two iron plates S at the sides of the contacts by means of a coil T of several turns of bare copper in series between the terminal and the upper contact. The contacts are partially enclosed in a chamber composed of arc resisting material fastened to the top and bottom plates of the magnet. The front of this chamber is open and the direction of the magnetic field in relation to the current is such that the arc is blown outwards. The copper blow-out coil is protected from the arc by means of a shield U, and a similar shield is fixed below the contact. For the arc resisting material of which this chamber is composed, many trials have been made; reconstructed soapstone was employed for some time, but this has now been superseded by a substance composed of asbestos and lime formed into a block under high pressure.

It will thus be seen that the whole contactor is built up on the fixed part of the magnetic circuit of the magnet, and the complete apparatus is suspended from the underside of the car body by means of three bolts through the top plate. It will also be noticed that the lower contact is in electrical connection with the frame, which is therefore alive. The suspending bolts are therefore insulated by suitable bushes and washers from the frame.

The contactor described and illustrated above contains no auxiliary contacts. These are arranged in various ways, but the most recent type is shewn in figure 203. This figure shews a pair of contactors mounted together on a single frame; one contactor only has auxiliary contacts. These are fixed underneath the pivoted levers and consist of two parts: the fixed contacts supported by the sides of the box of insulating material and the moveable plates which are arranged on a horizontal spindle and insulated therefrom, the spindle being connected by a suitable crank to the plunger.

The electro-pneumatic contactor made by the Westinghouse Co. is shewn in section in figure 204. As will be seen from this drawing, the arrangement of the compound lever for carrying the moveable contact is very similar to that already described, as also the flexible connection. The switch is operated by means of the pneumatic cylinder A with its piston B. Compressed air is supplied from the pipe P through the

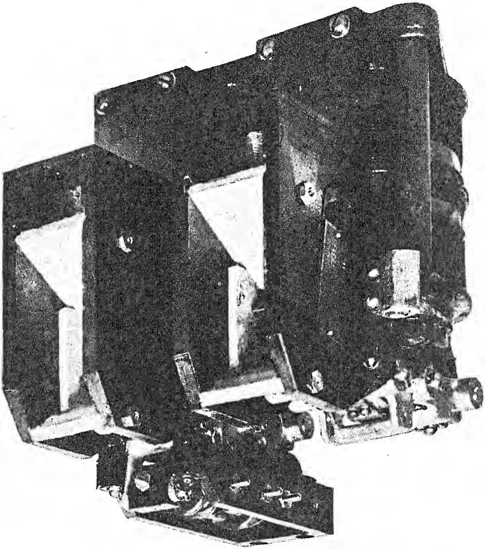


FIG. 203. View of a pair of magnetic contactors shewing position of auxiliary contacts or "interlocks." (Sprague-General Electric.)

valve V controlled by the valve magnet M. The auxiliary contacts are mounted at the back (to the right in the figure), the fixed portions C being attached to a finger board and the moving parts D being carried on insulation material attached to an arm extending from the piston rod. A number of these switches are mounted together in a case; figure 205 shews the front view of a switch group with the cover

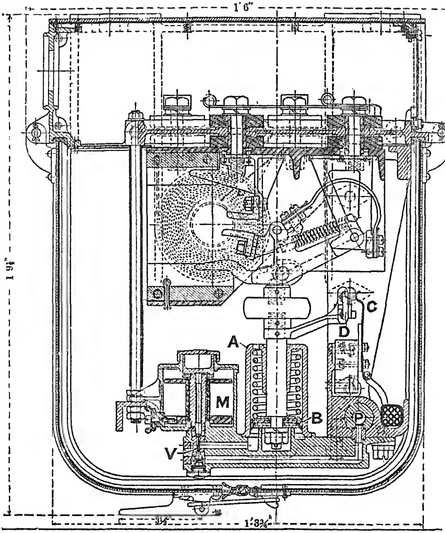


FIG. 204. Electro-pneumatic "unit switch." (Westinghouse.)

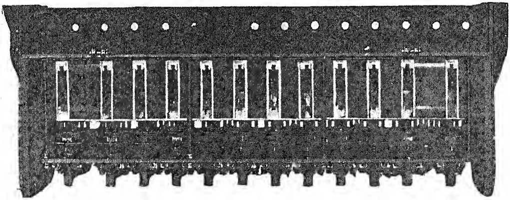


FIG. 205. Front view of a unit switch group with cover removed. (Westinghouse Electro-pneumatic.)

removed, and figure 206 the back view. In another form the switches are combined into a circular group, the units radiating out from a common centre; in this form, called the "turret" controller, a single coil provides the blow-out field for all the switches. These controllers were installed on the motor coaches of the Metropolitan Railway, but they were found in practice to be hardly equal to the very severe conditions, and they were gradually replaced by the switch groups shewn in figures 205 and 206.

"Throttle" or "limit" switches. In the Westinghouse unit switch system and in both the automatic systems of the General Electric Company there is necessary a "limit" switch which regulates the progression of the control through the agency of the current in one of the driving motors. This switch is necessarily a delicate piece of apparatus, and much care has been expended on its design, as the successful operation of the controller depends upon its precise working.

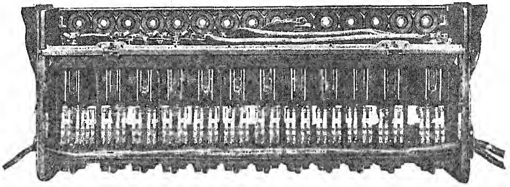


FIG. 206. Back view of a unit switch group with cover removed. (Westinghouse Electro-pneumatic.)

In studying the details of the designs described below, it is necessary to bear in mind that the switch has to occupy two different positions corresponding to two currents which only differ by a small amount. To make this point clear, consider the following example: let the motor current on the first step be 400 amperes; for this current the limit switch must be in such a position that the controller is checked; the switch must remain in this position until the current has fallen to say 320 amperes, when it must move over to its other position. The current will then rise to 400 amperes again and the limit switch must instantly respond. Now in the ordinary electro-magnet the pull depends not only on the current but on the position of the armature or plunger, and the magnet, unless specially designed to meet the conditions, will certainly remain open with a current of 400 amperes, if the spring has been set to pull it open at a current of 320 amperes. The problem is, therefore, to design a magnet that will change its position for the smallest practicable change of current.

The most obvious method of attacking the problem is to use some form of magnet in which the pull depends only upon the current and not upon the position of the armature. The drawback to this plan is that such magnets generally have a small pull and are not therefore very sensitive. The simplest form consists of a plunger inside a solenoid, the plunger being the only iron part of the magnetic circuit. In such a magnet there is a short range of movement, when the top of the plunger is near the centre of the solenoid, in which the pull does not vary with the position.

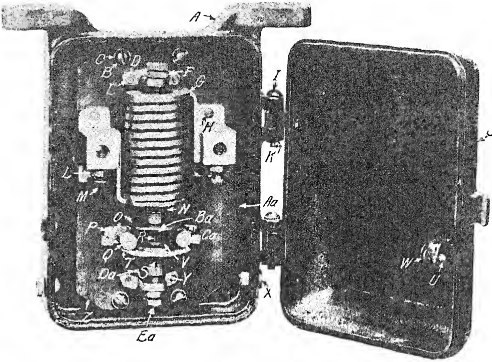
Another plan is to use an ordinary electromagnet with an iron circuit, and to arrange the armature in the same way as in long pull magnets, that is, so that the movement of the armature does not tend to decrease the length of an air gap, but diminishes uniformly the reluctance of the magnetic circuit. Another plan is mentioned below in connection with the Sprague-General Electric automatic relay system.

An example of the solenoid type is supplied by the automatic system of the General Electric Company. In this system the barrel of the master controller is connected to the operating handle through a spring. The barrel is also geared to a sort of "fly" after the fashion of the striking mechanism in a clock. This fly revolves inside a cylinder, being geared up with a high ratio, say 90 to 1; the cylinder is of iron with a thin lining of brass, and the fly is also of iron. The extremities of the fly have a small clearance as they revolve, and when a coil is energised a magnetic field is set up between the fly and the cylinder wall, which brings the extremities into actual contact and therefore stops the rotation. The limit switch which regulates the supply of current to this coil is shewn in figure 207. As will be seen it consists of a solenoid in which moves a plunger. This plunger carries an insulated contact plate, which bridges across two fixed contacts when the plunger is lifted. The magnetic pull acts against gravity, the pull amounting to about 6 oz. It is, therefore, obvious that the forces brought into play are comparatively small, and consequently the apparatus is somewhat sensitive.

A second type of limit switch is shewn in figure 208. This switch belongs to the Westinghouse electro-pneumatic system. The controlling force in this case also is gravity, and it is therefore quite simple to adjust the acceleration current to any desired value.

The magnetic circuit in this case is of the long pull type, consisting of a fixed core, a frame and a moveable core. The upper part of the moveable core or armature is tapered off so as to fit into a cavity in the fixed core, and consequently the magnetic circuit does not include any variable air gap between the armature and the core, the lines of force passing laterally from the upper part of the armature into the fixed

core. As the armature moves up, the number of lines of force increase uniformly and consequently give rise to a uniform pull. The armature movement is limited by a brass collar round the base of the upper part coming into contact with the fixed core.



A	Frame.	*Q*	Contact stud.
B	Screw for base.	*R*	Shaft.
C	Lock washer for base screw.	*S*	Spring for contact disc.
D	Shaft supporting bracket.	*T*	Contact disc.
E	Supporting bracket screw.	*U*	Cover latch pin.
F	Adjusting screw nut.	*V*	Small collar for shaft.
G	Operating coil, with terminals.	*W*	Spring for cover latch pin.
H	Screw for fastening terminal to base.	*X*	Soft rubber bushing for frame.
I	Hinge pin for cover.	*Y*	Large collar for shaft.
J	Frame cover.	*Z*	Base.
K	Spring cotter for cover hinge pin.	*Aa*	Shield for base.
L	Nut for terminal screw.	*Ba*	Adjusting nut for plunger.
M	Terminal binding screw.	*Ca*	Disc for plunger.
N	Plunger.	*Da*	Spring cotter for collar.
O	Lock washer for contact stud.	*Ea*	Adjusting screw for shaft.
P	Contact stud terminal.		

FIG. 207. Limit switch, Type DB 115, Form B2, for use with the Sprague-General Electric semi-automatic control system.

Figure 209 shews a third type, namely, that designed for use with the Sprague-General Electric automatic relay system. This switch contains several features of considerable interest, principally to enable an iron magnetic circuit to be used and therefore to make available relatively large forces. In the centre of the figure will be seen a coil of fine wire; immediately underneath this is another coil of bare copper

strip of three turns only, terminating in heavy terminals at the sides. The fine wire coil is connected in series with, and carries the same current as, the contactor magnets (fig. 194), and the thick coil is in series with one of the driving motors. The magnetic circuit consists of a plunger which carries the contact plate, and of the iron frame of the whole switch with a fixed core, precisely similar to the magnetic circuit of the contactor (figure 202). The function of the fine wire coil is as follows: when the plunger is in its lowest position the contact plate bridges the two fixed contacts and completes the circuit of train wire No. 1 (figure 194); the fine wire coil is connected in this circuit, and therefore

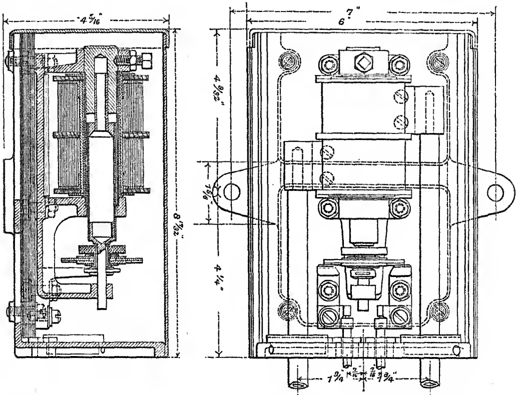


FIG. 208. Limit switch for use with the Westinghouse electro-pneumatic unit-switch control system.

in this position this coil is energised. As soon as the plunger lifts this circuit is broken, and the excitation of the magnet depends solely on the motor current flowing in the three series turns, whereas in the lower position of the plunger the excitation depends upon both coils. This device compensates for the large difference of pull per ampere turn in the two positions, so that the same motor current will give rise to the same pull in both positions. In this way the forces can be much greater than in the limit switch first described, being about 1 lb. as against 6 oz.

In the working of this limit switch two conditions are essential (1) that the switch shall close at the same rate as the contactor which

is being energised and (2) that the fine wire coil shall continue to carry current until the plunger has risen sufficiently to complete its motion under the influence of the series coil only. If the first of these conditions is not fulfilled either two contactors may close in succession before the control circuit is opened or a single contactor may start vibrating between an open position and a position in which the switch is half closed.

To meet this condition the plunger is mechanically connected to a small piston working in a cylinder placed at the top of the switch, the cylinder being provided with adjustable throttle valves whereby the speed of the motion can be controlled. To meet the second condition, the contact plate has a certain amount of lost motion; the plate is an iron disc coated with silver and is mounted on an insulated sleeve on

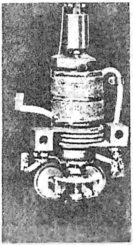


FIG. 209. Limit switch for use with the Sprague-General Electric automatic relay control system.

the plunger stalk and connected thereto by a helical spring underneath it. The contacts are also of iron with suitable tips, and each one is magnetised by means of a coil of fine wire. Thus the contact plate is held in place by these magnetised contacts while the plunger rises, until the force of the compressed spring is sufficient to overcome the magnetic pull.

Reversers. These are generally in the form of barrels or their equivalents, and are operated either by magnetic or pneumatic means according to the system employed. They are not designed for breaking currents and have no magnetic blow-outs, except for the small auxiliary contacts. The General Electric Company's form is shewn in figure 210 and that of the Westinghouse in figure 211.

Dead Man's Handle. This device is of considerable importance commercially, in that it is designed to permit the entire control of

the train to be in the hands of one man. To be able to dispense with the services of a second driver and to that extent to reduce the working expenses is a strong point in the discussion of the advantages of electrification. The Board of Trade would not permit a railway company to put only one man in charge of a train, unless some provision were made for ensuring the safety of the train in the case of the sudden disablement of the driver.

The device which has been introduced for this purpose is called the Dead Man's Handle, and in one form consists of a press-button in the handle of the master controller. The pressure of the driver's hand depresses this button into the position necessary for the normal operation of the train; but if the driver removes his hand while the master controller is in any of the running positions, or even in the "off" position unless the reversing handle is also at "off," the rising of the button cuts off current from all the control circuits and puts on the air brakes.

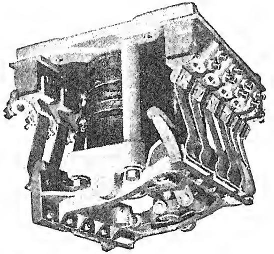


FIG. 210. Magnetic reverser for use with the Sprague-General Electric control systems.

The arrangement of levers and contacts in the master controller whereby the current is cut off from the control circuits is comparatively simple, the only requirement being that the rising of the press-button in any position except "off" shall open a circuit. The simultaneous application of the brakes is performed by connecting the press-button with a valve in such a way that the raising of the button in any of the running positions opens the train pipe to atmosphere.

Too much space would be required to illustrate the mechanism in detail; the above general description will be sufficient to indicate the requirements of the apparatus.

In another form, viz. that adopted by the Westinghouse Company, the device consists of a spring whereby the master controller is forced

back to the "off" position whenever the driver removes his hand. In this position the brakes are applied automatically (see pages 291, 331).

General discussion of automatic control. From the above descriptions of train control it will be seen that in many of the systems

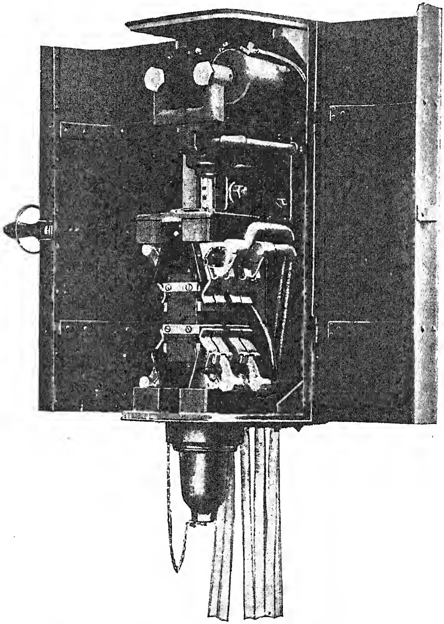


FIG. 211. Pneumatic reverser for use with the Westinghouse electro-pneumatic control systems.

some device has been included which provides for automatic regulation of the rate of switching on.

These devices may be divided into two groups, first those which control the train by means of the motor current of the driver's car, and

secondly those which permit each car to control itself independently of the others.

Some engineers dislike the automatic operation in any form, and more particularly in that form which allows each car to control itself. It is argued that on this system the driver has no knowledge of what is actually taking place on other cars than his own. The driver should know for certain that all the controllers of a train are in the same position and that they should under all circumstances correspond to the position of the master controller. In the automatic system, if any throttle relay sticks in one position, that controller will progress as fast as possible until the automatic cut-out opens or the fuse burns out.

Against these arguments it may be replied that every system provides for at least three definite positions to which all the controllers can be brought, viz. "off," "full series" and "full parallel," and that the driver should never allow the controller on any system, automatic or otherwise, to remain in any other position. The sticking of the throttle relay is the only extra danger, as far as can be seen, introduced by the automatic arrangements, and experience must decide to what extent it is a real danger. Even this danger scarcely exists in the case of the semi-automatic system in which the current of one motor checks the driver in switching on.

On the other hand, the arguments in favour of automatic switching are, first, smoothness of start, secondly, economy in power consumption, and thirdly, the possibility of employing less skilled drivers, who need only watch the signals and pay attention to the driving of the train without troubling about the controller movements.

The balance of advantage must rest a good deal on the reliability of the apparatus, and it is probably too soon to expect a final decision.

CHAPTER 15.

DETAILS OF MOTOR CAR EQUIPMENTS ON DIRECT CURRENT RAILWAYS.

The details of the equipment of a motor coach operated on a direct current system include besides the control apparatus proper several parts which require special reference. The various systems of control have been dealt with in the preceding chapter, more particularly with regard to actual controllers, whether main controllers, or master controllers with their corresponding motor switches. In this chapter the various accessories are considered, including all the other parts of the electrical equipment.

List of parts. The following is a complete list of parts as supplied with a unit switch multiple control system. With other systems various items will not be required, as will be obvious on inspection. The system assumed is for a single motor coach on a 500 to 600 volt direct current supply with both poles insulated.

1. Four positive collector shoes, one on each side of each bogie.
2. Two negative collector shoes, one in the centre of each bogie.
3. A flexible cable (sometimes called a "pigtail") from each shoe, positive and negative.
4. Four shoe fuses, one for each of the positive shoes. Fuses are not fitted to the negative shoes.
5. Two bus lines, one positive and one negative.
6. One bus line fuse, for the positive bus line.
7. Four bus line sockets.
8. Two bus line jumpers.
9. Two bus line junction boxes.
10. Two main motor switches, one positive and one negative.
11. Two main motor fuses, one positive and one negative.
12. One automatic cut-out for the motor circuit.
13. One automatic cut-out switch, or overload reset switch, which enables the driver to close all the automatics on the train.

14. Motor controller, consisting of reverser, unit switches or contactors, rheostats and power cables.
15. One or two master controllers, according to requirements.
16. One double pole control circuit switch for each master controller.
17. Two control circuit fuses, one positive and one negative, for each master controller.
18. One control circuit rheostat (this is not required when the unit switches are controlled with a low tension current).

18*a*. Two storage batteries, with battery charging relay and resistance (these parts are not required when the control circuits are supplied from the bus lines).

19. A control circuit cut-out switch.
20. A multiple core control cable or train line.
21. A train line junction box at each end of the car, if both ends are provided with master controllers.
22. Four train line sockets, two at each end.
23. Two train line jumpers.
24. One motor driven compressor.
25. One automatic compressor governor.
26. One compressor governor cut-out switch.
27. One compressor switch.

In addition to these parts there are the wiring for lights, internal and external, and for heating and the necessary switches to control these circuits. There is also the usual equipment of driver's brake valve, and the brake piping, couplers, reservoirs, etc.

Collector shoes and fuses. The collector shoes are dealt with below; it may be said here, however, that they serve to collect current from the third and fourth rails for all purposes to which it is applied on the car. These shoes are always capable of movement so as to be able to keep in contact with the conductor rail in spite of irregularities of level. This makes it necessary that the support should be hinged in some way, and, hence, a flexible connection is provided so that no current need pass through the hinge. This connection consists of well insulated extra flexible cable, and provides a path between the shoe and the shoe fuse. This fuse may be of any convenient type, arranged so as to be accessible from the track, and usually consists of a stout strip of copper, or a pair of copper wires, in a case of fireproof insulating material, the side of the case being open outwards from the car. This fuse may conveniently be mounted on the wooden

beam to which the collector shoe is attached. Figure 212 shews a side view of a fuse manufactured by the British Thomson-Houston Company.

Bus lines. The bus line or lines are the equivalent of the bus-bars on a station switchboard. These lines run the whole length of the train; the connections from the collector shoes correspond to the incoming feeders or the leads from the generators, and the motor connections on each car correspond to the outgoing feeders. The bus line connection boxes join the shoe leads to the bus line. This connection might be made a permanent T joint, but in that case it would be difficult to disconnect. An alternative method is to use a split casting which can be clamped round the cable ends. This method may give rise to trouble if the clamping connections get loose.

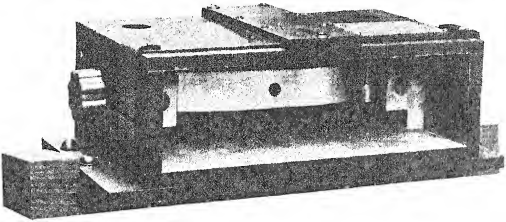


FIG. 212. Main fuse in fuse box. (British Thomson-Houston.)

The bus lines which run throughout the train are connected between coaches by means of flexible connections. The universal method is to connect the cables on the car to sockets attached to the headstocks, and to use a flexible cable with a plug at each end to join up the two sockets on adjacent cars. These flexible connections with two plugs are called "jumpers." Figure 213 shews a pair as manufactured by the Westinghouse Company, the male part or the coupler socket being fixed to the coach and the female part or coupler being attached to the jumper. The coupler socket is closed when not in use by means of a hinged cover, which is so designed that when the coupler is inserted it is held in position by means of a catch on the socket cover. A similar pair of couplers, as made by the British Thomson-Houston Company, is shewn in Fig. 214.

It should be remarked that bus lines are not allowed by the Board of Trade on "tube" railways. On surface railways they are sometimes used, depending upon the arrangement of the conductor rails. If the

gaps in the conductor rails due to junctions and crossings are too great it is impossible for a single coach to maintain constant connection, and it becomes a matter of choice whether it is better to allow the circuit of each car to be broken as it passes the gap, or to join up all the collector shoes on the different cars by means of bus lines. The latter alternative involves heavy cables on all cars, whether motor or trailer, and

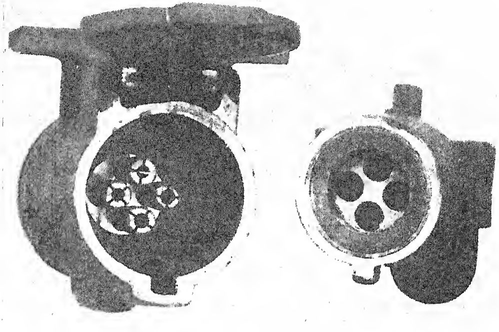


FIG. 213. Bus line coupler socket and coupler. (Westinghouse.)

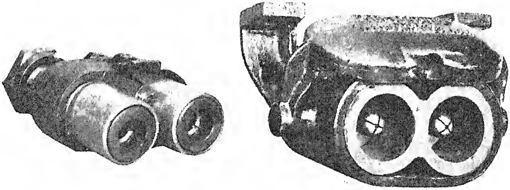


FIG. 214. Bus line coupler sockets and couplers. (British Thomson-Houston.)

flexible connections between the cars capable of carrying heavy currents. The former alternative is certainly simpler as far as the main power wiring is concerned, but it may lead to very severe jerking as the first motor car and then the rear motor car pass over the gap. If it is practicable to coast over the gaps this may be avoided, otherwise a bus line is necessary.

Wiring for lighting and heating. In this connection it is advisable to consider the arrangement of the car wiring for lighting and heating. If it can be arranged it is best to design this wiring so that the lights on a trailer car shall not all be extinguished when the motor car which supplies it is passing over a gap. For this purpose it is customary, when there is no bus line, to divide up the lamps into two sets, one of which is supplied from the motor car at one end and the other from the motor car at the other end of the train. These two sets on all the trailer cars must be kept electrically separate, otherwise the electrical connection between them would be equivalent to a bus line, and a slight difference of potential between the two rail sections might cause a heavy current to flow from one motor coach to the other through the lighting wiring. This wiring is, naturally, not designed to stand heavy currents, and the result would be a blown fuse and the extinction of the lights.

Several arrangements have been devised to deal with this requirement. Figure 215 shews diagrammatically the method adopted on the Metropolitan Railway trains, which at first were not fitted with bus lines. On the motor coach to the left of the diagram there are three leads, A, B and C, of which B is connected through a fuse to the negative shoe and C through a similar fuse to the positive shoe. A can be connected to the negative shoe by two double-pole throw-over switches through the two 15 volt batteries connected in parallel. [This arrangement provides for the constant charging of the battery which is used for supplying current to the control circuits.] All the lights in the motor coach are supplied from lead A, but the heaters are in two divisions, each division taking current from different positive and negative leads. On the trailer car there are two pairs of leads as shewn, the two sets of lights and heaters being connected up to the different pairs. Couplers are provided between the cars for joining up the different circuits. It will thus be seen that the motor coach is always lit, and that the trailer always has at least half its lights supplied, one pair of wires being connected to the front motor coach and the other pair to the back.

When the train is split up into two parts with only one motor coach in each the two couplers are connected together at the free end of the trailer car as shewn in dotted lines.

Another arrangement is shewn in figure 216. This has been designed by Messrs Siemens Brothers Dynamo Works* for the single phase electric trains on the Heysham-Morecambe line of the Midland Railway. As before, duplicate lighting leads are provided and connected to the two sets of lights and heaters. The particular feature of

* This arrangement is the invention of Mr A. M. Duke.

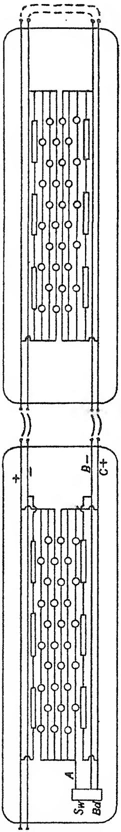


FIG. 215. Arrangement of wiring for lighting and heating on trains without bus line connections. (Westinghouse.)

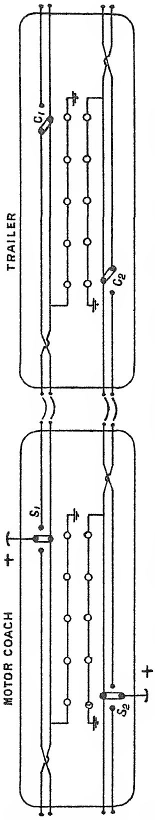


FIG. 216. Siemens arrangement of wiring for lighting on trains without bus line connections.

this system is the arrangement of the throw-over switches between the duplicate leads and the lighting circuits. Either of the two sets of lights can be connected to either of the duplicate leads without there being any possibility of a connection between the duplicate leads. This system has the advantage that no special arrangement is required for connecting the duplicate leads when there is only one motor coach on the train. In the figure S_1 and S_2 represent two three-way switches on the motor coach, C_1 and C_2 two-way switches on the trailer connected up to the duplicate lighting leads as shewn. The centre contact of the three-way switches is connected to the source of current (collector shoe or overhead trolley). In the positions shewn in the figure all the lamps on the motor coach are being supplied from the collector shoes on that coach; the upper set of lamps on the trailer obtain current from this motor coach and the lower set from another motor coach to the right. If there is no other motor coach the switch C_2 is thrown over into its other position, and then all the lamps on the trailer can be lit from the one source.

Automatic cut-outs. The automatic cut-out for the motor circuits depends upon the type of system in question; for the electro-pneumatic system as described in the previous chapter a pair of pneumatic unit switches with special auxiliary contacts and tripping devices is required; for the contactor system it consists of a pair of contactors connected in parallel. Figure 217 shews a circuit breaker of the British Thomson-Houston Company type DB—101—A. This does not contain in itself any automatic gear, as it is operated by the control wires.

Control wiring, couplers and jumpers. The other parts of the main controller have already been dealt with in the previous chapter; the resistances for the motor control are usually of the grid type, as described in chapter 4, and are placed under the coach body or in the driver's cab as determined by the space available.

The train lines contain the necessary wires for controlling the motors from the master controllers. These wires are made up together into a multicore cable, and it is usual to cover the separate cores with insulation material having distinctive colours so as to facilitate proper connections to the various parts of the apparatus and to the couplers. The couplers and jumpers are similar to the bus line couplers and jumpers, except that there are a number of connecting points insulated from each other, instead of a single connection. Figure 218 shews a seven-point train line coupler for the Westinghouse electro-pneumatic unit-switch system. It will be seen that on the jumper coupler there is a projection at the bottom which fits into a recess in the coupler socket, so that there can be no mistake as to which way up the coupler shall be inserted. The actual connections in the socket are split copper pins, which are bolted

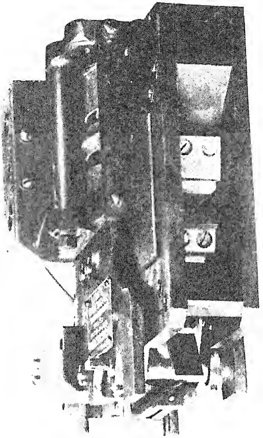


FIG. 217. Main circuit breaker for direct current railway car equipment. (British Thomson-Houston.)

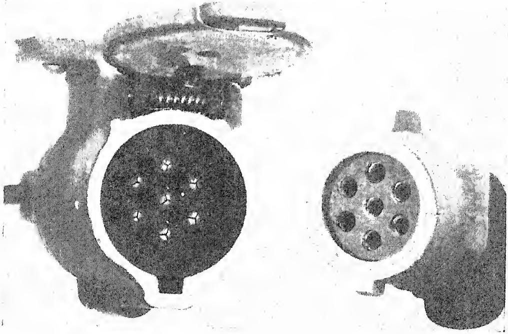


FIG. 218. Seven point train line coupler socket and coupler. (British Westinghouse Company.)

to a block of insulating material by nuts at the back. The connections in the coupler are small spring sockets sunk into an insulating block.

The methods of connecting train wires from one coach to the next are important. The chief requirement is that it shall be possible to turn each coach end for end without in any way affecting the control of that coach or of the other coaches in the train. Thus if a motor coach be turned round it is necessary that all connections between a master controller on another car and its own contactors or switches shall remain unchanged, but that the connections to its reverser shall be changed round. Thus it is necessary to discriminate between the speed controlling and the direction controlling wires. There are two alternatives (1) to duplicate the couplers and jumpers, (2) to cross the wires in the couplers and in the jumpers.

(1) The method generally adopted is to use two couplers at each end of each car, the two couplers being placed away from the centre one on each side. Thus consider the diagrams in figure 219, shewing the wiring in plan, in which the four couplers are indicated by A, B, C and D, and the seven train wires by the lines marked 1, 2, 3 ... 7, of which 1, 2, 3, 4 and 5 are speed wires and 6 and 7 direction wires.

For the sake of clearness it is best to give separate marks to those points in the coupler sockets and couplers which are connected to the direction wires; call these points F and R and let it be understood that if current be supplied to any point marked F in a socket by an observer standing in front of that socket the car will tend to run towards the observer, and *vice versâ* for R. Then any one direction wire on a car must be connected to F at one end and R at the other end, so that the car may be turned end for end and still run towards or away from the observer.

In whatever way the connections are made it is essential that all cars shall appear the same to an observer whichever end he looks at. With this condition fulfilled, several arrangements are possible similar to figure 219. In this diagram crossings may be arranged variously in the train wires, in the connections to the couplers, and in the jumper, but in each case it should be seen that the necessary requirements are fulfilled; with these variables it is possible to obtain a considerable number of combinations both for the train wires for speed and the train wires for direction. Thus, indicating by × that wires are crossed, and by — that wires are not crossed, there are the following possibilities:

Speed wires.

Arrangement	Train wires	Connections to couplers A	B	C	D	Jumpers
1	×	—	—	—	—	×
2	×	×	—	—	×	—
3	—	×	—	×	—	—

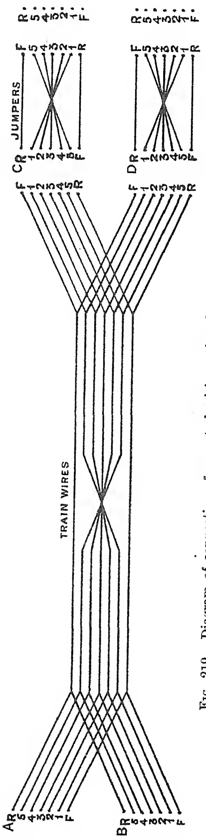


FIG. 219. Diagram of connections for control wiring using duplicate couplers and jumpers.

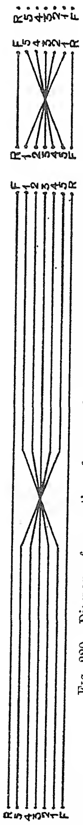


FIG. 220. Diagram of connections for control wiring using single couplers and jumpers.

Direction wires.

1	—	—	—	—	—	—
2	—	×	—	—	×	×
3	×	×	—	×	—	×

Any one of these arrangements of direction wires is compatible with any one of the arrangements of the speed wires.

(2) The alternative method in which there is only one jumper between each pair of cars has not so many possibilities. If figure 220 represents the wiring in plan as before, it will be seen that this is the only arrangement possible consistent with the requirements. If therefore there are in any system examples of both methods, the jumper shewn in figure 219 is the proper one, as it is the only one that will suit both alternatives.

In practice, of course, the points in the couplers are not spread out in a single horizontal line, but are grouped up within a circle; the same principles however apply to crossing the wires through a vertical line through the centre of the coupler.

Of the two alternatives the first has the advantage inherent in duplication in that any fault in one jumper does not incapacitate the train, and the second has the advantage in first cost. Of the various possibilities in the first alternative, the first in each case is probably the best, as the disposition of the wires in all coupler sockets is the same, independent of their positions on the coach.

Collector shoes. In general, collector shoes are of two types, that in which a cast iron block is hung by a link at each end, the block being oblong, the long side being parallel to the length of the conductor rail, and that in which the actual contact part consists of a flat cast iron plate hinged along one edge and attached thereby to the fixed part of the collector.

On electrical trains in this country the former type is chiefly used. Figure 221 shews a collector shoe as supplied to the Great Northern and City Railway by the British Thomson-Houston Company. The contact part consists of a cast iron block 16 inches long by 6 inches wide and about $1\frac{1}{8}$ inches thick. This is supported by two links from a metal framework, which is bolted to a wooden beam which in turn is bolted to extensions of the axle boxes of the truck. The shoe has freedom of motion in a vertical direction, in its lowest position being about three-quarters of an inch below the level of the conductor rail. The weight of the shoe is about 35 lbs., and as it hangs free this represents the pressure on the conductor rail. The wooden beam in this case extends in front and behind the axle boxes, and supports a shoe at each end. The distance from the shoe centre to the axle box centre

is 2 ft. 4¼ in., and the wheel base being 6 ft. 1 in. the front shoe is 5 ft. 4¾ in. in advance of the bogie centre.

In some cases the shoe is carried midway between the axles, as for example on the Liverpool to Southport line, and on the Metropolitan District Railway.

The collector shoe designed by Messrs Siemens Schuckert for the Hoch- und Untergrund Bahn in Berlin is of the same type, but has one or two special features. It is hung in the usual way by links from the axle boxes, so that a considerable range of movement is possible. When it rests on the conductor rail it is, of course, connected to the other collector shoes by means of the car wiring; but when the shoe is hanging free it is entirely disconnected from the car circuits by means

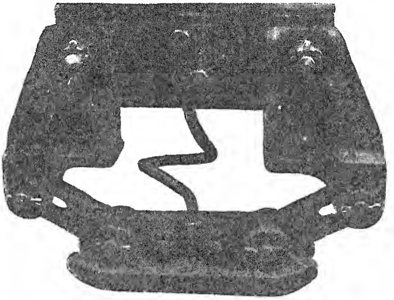


FIG. 221. Positive collector shoe as used on the Great Northern and City Railway. (British Thomson-Houston.)

of a simple switch, which depends on the position of the shoe, so that there is no danger of electric shock to anyone working on the line at that point. By means of another device of a similar character, all the lights in the train are switched on when the train enters a tunnel. For this purpose the third rail is raised in the tunnel about 50 millimetres above its usual level in the open; this change of level raises the collector shoe above its normal position, and by so doing makes a connection with the lighting circuits.

The other type of collector shoe is illustrated in figure 222, which represents that in use on the electric locomotives of the New York Central and Hudson River Railroad. It consists of a vertical cast iron plate bolted to a wooden beam supported from the locomotive frame,

and a horizontal cast iron plate hinged to the fixed vertical plate. The latter has a vertical movement of about 2 inches, and a powerful spiral spring round the hinge tends to maintain a central position, so that the shoe may collect from the upper or lower surface of the third rail (see figure 248, page 361). A flexible cable makes connection between the shoe and the wiring. Four of these shoes are mounted on the locomotive, and together they collect current up to about 5000 amperes

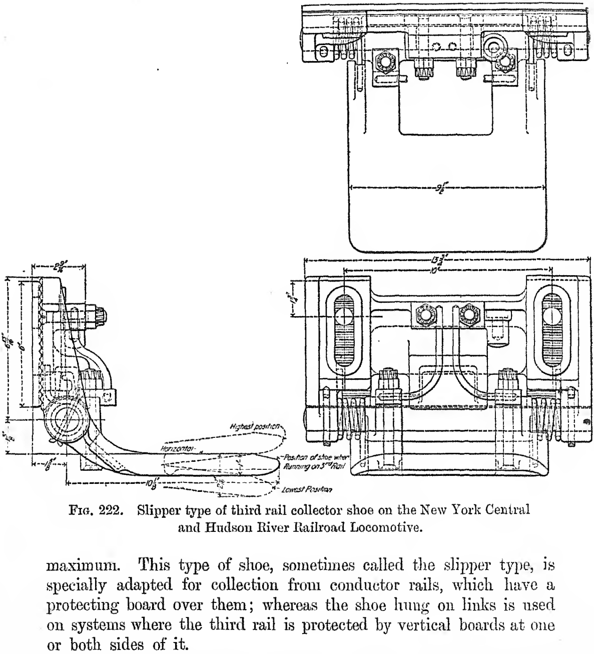


FIG. 222. Slipper type of third rail collector shoe on the New York Central and Hudson River Railroad Locomotive.

maximum. This type of shoe, sometimes called the slipper type, is specially adapted for collection from conductor rails, which have a protecting board over them; whereas the shoe hung on links is used on systems where the third rail is protected by vertical boards at one or both sides of it.

In systems where both poles are insulated, negative shoes are required. These are of the same type as the positive shoes, but in cases where the fourth rail is in the centre of the track, the shoe is

supported by means of a wooden beam which is bolted to a cast iron bracket. This bracket is shaped so as to be bolted to the casing of the motor, the hollow in the casting being for the accommodation of the car axle. The arrangement is shewn in figure 223.

Another method, due to the Westinghouse Company, is used when the collector shoes are to be arranged in front of the bogie instead of between the bogie wheels. According to this method the two axle boxes on each side support a steel channel which is prolonged at the front end of the bogie. These two channels at the front end are bent downwards and inwards after clearing the wheels, and their ends are bolted to a cross beam of wood which carries the shoes and the shoe fuse. The two positive shoes are fixed at the two ends of the beam, and the negative shoe in the centre.

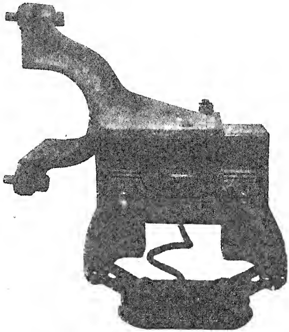


FIG. 223. Negative collector shoe for central conductor rail. (British Thomson-Houston.)

In some cases the collector gear consists of overhead bow collectors after the style of the tramway bow (illustrated in chapter 4). In order to enable it to collect enough current without overheating at the point of contact, the number of contact bars is multiplied in various ways. Two complete bows may be mounted on each car, one at each end, and if necessary each bow may be fitted with two or more contact bars. Or again, there may be two overhead wires in parallel, current being collected from both wires by each collector bar.

Power wiring. The wiring of motor coaches on electric railways is a matter of considerable importance. As with other details of electric

railway apparatus, this has been evolved from the regular practice adopted in the case of electrically equipped tramcars, the different conditions requiring different treatment.

These different conditions are chiefly as follows: the equipments are on a very much greater scale, and the service conditions on which the cars work are those of a railway rather than a tramway. The first of these differences requires no comment. The second makes itself felt principally in the necessity for guarding against any possibility of fire. Serious accidents (on the Liverpool Overhead Railway and on the Paris Metropolitan Railway) have in times past been caused by fires which have arisen from overheating or fusing of the electrical apparatus. The danger is present more especially in the case of "tube" railways, but it is sufficiently serious in railways of other descriptions.

Unless special precautions are taken, the wiring is perhaps one of the most obvious sources of danger. The motors are generally totally enclosed, and the controlling apparatus is such that fireproof protection is essential. At first, however, no particular attention was paid to the wiring; it was simply cleated to the under surface of the car body.

The method generally adopted now is to provide a complete metallic protection for the whole of the wiring, generally by inserting all the cables in wrought iron pipes or tubes. This method is perfectly simple except at joints or places where flexible connections are required. As far as possible joints are made in a special iron-clad junction box, the iron pipes being brought up to the sides of this box and terminating there in a threaded end clamped to the box by means of lock nuts. This applies also to the cases which contain the control apparatus and the various switches, relays, etc. Special provision must be made to avoid abrasion of the insulation at the points where the cables issue from the pipes. On the New York Subway the pipes are provided with "bell-mouth" ends, which are screwed on to the pipe ends; between the cable and the bell mouth a soft rubber gasket is inserted as a protection. Figure 224 illustrates a bell mouth attached to a pipe end, where the enclosed cable enters a case.

Another difficulty arises where the leads have to be taken from these pipes to the motor terminals, as some flexibility in the connection is necessary. Assuming that two motors are mounted on a truck, eight flexible leads are required between the truck and the fixed car wiring. These flexible leads can be protected by a flexible sheath or armouring, and the junctions with the motor leads may be made within this armouring by means of suitable connectors.

The pipes are sometimes, as in the case of the steel cars on the New York Subway, covered inside and out with hard enamel which

serves as a protection against rust. They may be supported by clamps or cleats from the under surface of the car body, or by special cross beams in the underframing; but care should be taken that they are easily removeable and are accessible for repair and examination*.

On the Metropolitan District Railway the main wiring is run in drawn steel tubes, but the rheostat and the contactor wiring is contained in wooden troughs lined with uralite.

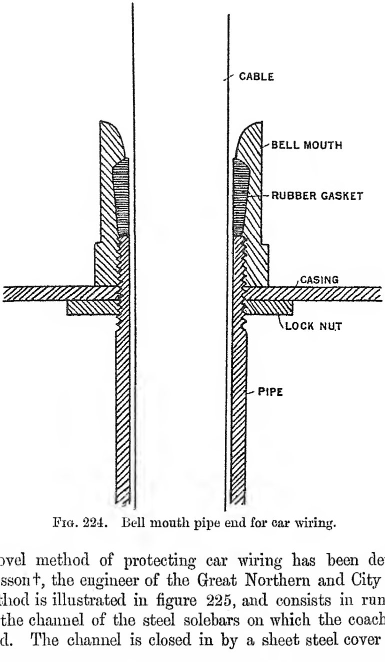


FIG. 224. Bell mouth pipe end for car wiring.

A novel method of protecting car wiring has been devised by Mr Brousson†, the engineer of the Great Northern and City Railway. This method is illustrated in figure 225, and consists in running the wires in the channel of the steel solebars on which the coach body is supported. The channel is closed in by a sheet steel cover as shewn

* For further information as to the car wiring on the New York Subway, see *Street Railway Journal*, March 4, 1905.

† The authors wish to express their thanks to Mr Brousson who has supplied them with particulars and drawing of his system of car wiring.

in the drawing, and thereby forms a closed conduit. In this space the wires are supported by wood cleats, spaced about one foot apart, and thus run as required from end to end of the coach. Branches are taken off to the motors and rheostats, through holes bored through the web of the solebar, and the emerging cables enter a sheet steel conduit which protects them to their destination.

Air brakes. Compressed air. The air brakes on an electrically driven train are naturally an important item. The elimination of the

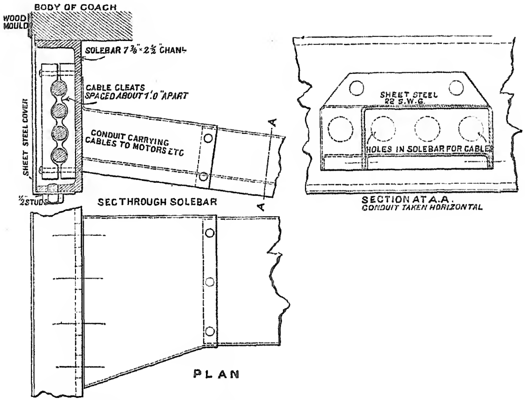


FIG. 225. Arrangement of car wiring in the steel coaches of the Great Northern and City Railway.

steam locomotive removes the usual means for obtaining a vacuum or compressed air, and it is necessary to provide some substitute.

As far as compressed air brakes are concerned there are three alternatives, (1) the storage system, (2) axle driven compressors, and (3) motor compressors mounted on the train, the compressors being driven by electric motors.

The storage system has a limited field of utility as applied to railways, as it consists of supplying the train with a store of compressed air from a stationary reservoir at the terminus, or other convenient place. As an example of this system the case of the

Waterloo and City Railway may be quoted*. The stationary compressors are situated at the Waterloo end, there being four in all, one of which is a spare. These pumps deliver into a reservoir of 250 cub. ft. at 140 lbs. per sq. in., from which air is supplied to the trains at a pressure of 100 lbs. per sq. in. once every four hours. The cost of power for compressing air for 800 applications of the brakes per day is about one shilling.

Axle-driven compressors can be used on trains which are worked under conditions similar to those on tramways, that is where the speed is not excessive. Figure 226 shews an axle compressor made by the Westinghouse Brake Co., suitable for cars where the speed of the axle does not exceed 150 r.p.m., that is where the speed of the car is not

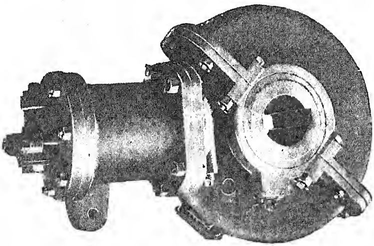


FIG. 226. Axle compressor. (Westinghouse Brake Co.)

greater than $13\frac{1}{2}$ miles per hour with a 30 inch wheel. The following are the particulars of this compressor:

Size of cylinder	Capacity	Overall dimensions	Weight
$6\frac{1}{4}$ in. diam.	$9\frac{1}{2}$ cub. ft. of free air at 150 r.p.m.	length 31 in. height $20\frac{1}{2}$ in. width 9 in.	2 cwt.

The most usual brake equipment for a compressed air system on electric trains consists of a motor-driven compressor.

In its simplest form this motor compressor replaces the steam-driven compressor usually mounted on the steam locomotive. The general arrangement of the apparatus is shewn in figure 227, in which the left hand part of the diagram represents the equipment of a motor car, and the right hand part that of a trailer car. The figure does not

* See "The Electrical Equipment of the Waterloo and City Railway" by B. M. Jenkin, *Proc. Inst. C. E.* vol. 139; and a paper by Herbert Jones before the Tramways and Light Railway Association, *Electrician*, February 24, 1905.

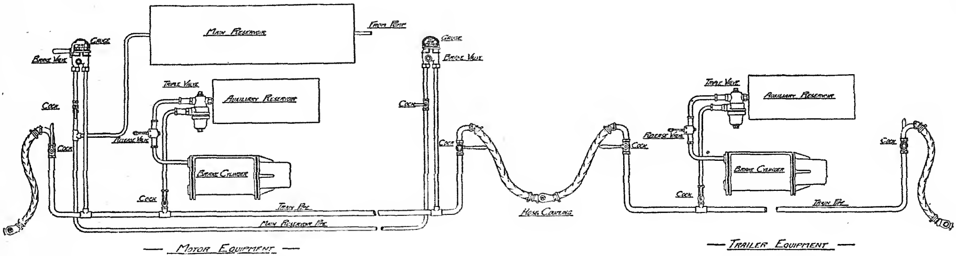


FIG. 227. Diagram of brake equipment using a single motor compressor. (Westinghouse Brake Company.)

call for any special explanation beyond drawing attention to the difference between the two equipments. The motor car contains a motor compressor, a main reservoir, a driver's valve at each end, and a main reservoir pipe connecting these two valves.

In general, electrically driven trains usually contain more than one motor coach, and the principle of division into complete units is carried into effect as regards the motor compressors. For example, consider the case of an electric train consisting of a motor coach at each end and a number of trailers in the middle. Provision is very often made for splitting such a train into two independent units, each with one motor coach and several trailers. It is necessary therefore to mount on each motor coach a motor compressor, and at the same time the arrangement must be such that when the two independent units are made up into a single train, the two motor compressors can operate in parallel. For this purpose two train pipes are installed, running the whole length of the train, one for the ordinary purpose of applying the brakes, and the other for connecting the two main reservoirs. Thus, if one compressor breaks down, the corresponding reservoir can be supplied from the other compressor through the equalising train pipe. The general arrangement of the brake equipment supplied by the Westinghouse Brake Company to the Metropolitan Railway (London) is shewn in figure 228, from which a good idea of the various parts can be obtained. In addition to those already mentioned, there are a few special parts, as follows:

The automatic switch and governor regulates the working of the motor compressor. This governor depends for its action upon the pressure in the reservoir. If through an application of the brakes the pressure falls, the governor throws over a switch which starts the compressor motor; when the pressure has risen to the proper value, the current is again cut off. These governors are generally set to maintain a pressure which will not vary more than 5 to 8 lbs. from the maximum.

The emergency brake magnet works in conjunction with the electrical control of the train on the Westinghouse electro-pneumatic system. This brake magnet is energised from the master controller if the handle of this controller is allowed to come to the "off" position, and when energised opens the brake relay valve, thus applying the brakes all down the train. The master controller handle is connected to a spring such that if the driver lets go, the handle will fly back to the "off" position.

The control reservoir supplied from the main reservoir through a reducing valve supplies compressed air for the working of the electro-pneumatic control system.

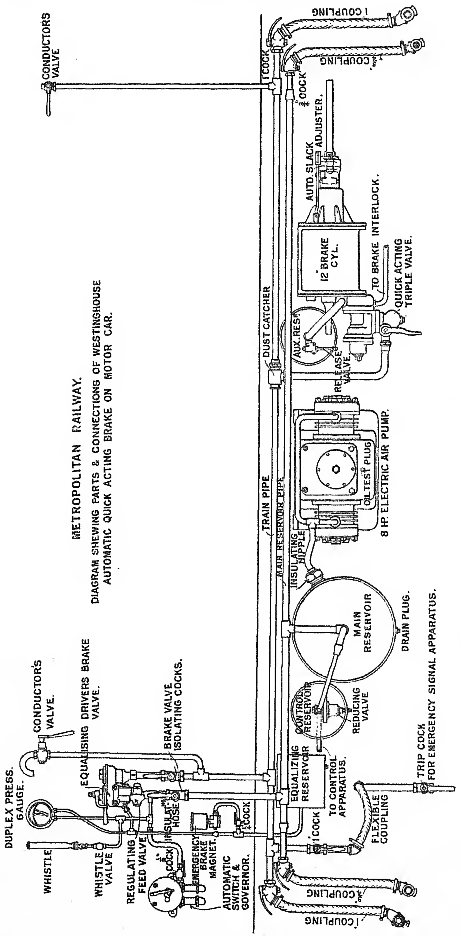


FIG. 228. General arrangement of brake equipment using several motor compressors and an equalising train pipe. (Westinghouse Brake Company.)

A trip cock is provided, and so placed on the motor bogie that if the train overruns a signal, the cock comes into contact with a fouling bar on the track, and opens the train pipe to atmosphere and applies the brakes.

The Westinghouse Brake Company make four sizes of motor compressor, particulars of which are given in the following table:

Class G	Diam. of cylinders	Stroke	R.P.M.	Volts	Capacity, free air per minute	Dimensions			Weight lbs.
						Length	Height	Width	
No. 1	3″	2″	300	500	5 c. ft.	22″	10″	18″	357
No. 2	$3\frac{1}{2}$″	3″	300	500	10 c. ft.	25″	13″	24″	560
No. 4	5″	3″	300	500	20 c. ft.	33″	14″	25″	993
No. 8	$6\frac{1}{2}$″	4″	250	500	38 c. ft.	33″	18″	31″	1478

Figure 229 shews a general view of the No. 8 motor compressor. The motor can be turned round through 180° so that the compressor

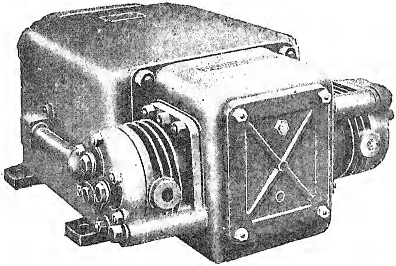


FIG. 229. General view of motor compressor. (Westinghouse Brake Company.)

can be bolted under a car direct to the frame, or can be placed in the driver's compartment.

Vacuum brakes. The alternative system of brakes in general use on railways, viz. the vacuum brake system, can be adapted to the requirements of electric railways. In the adaptation it is necessary to provide a substitute for the apparatus carried on the steam locomotive, which usually consists of two steam ejector exhausters. One of these is a comparatively small one, and serves to maintain the vacuum in the

brake cylinders against leakage in the train pipe and elsewhere. The other is comparatively large, and is only required after the application of the brakes to effect a release by withdrawing the air that has been admitted into the train pipe and brake cylinders. To release the brakes quickly it is necessary that the vacuum should be restored as soon as possible, and hence the large ejector has a considerable capacity. This peculiarity of the vacuum system requires special provision when the system is adapted to electric trains; but in several instances these brakes have been fitted and no drawbacks or disadvantages have been experienced.

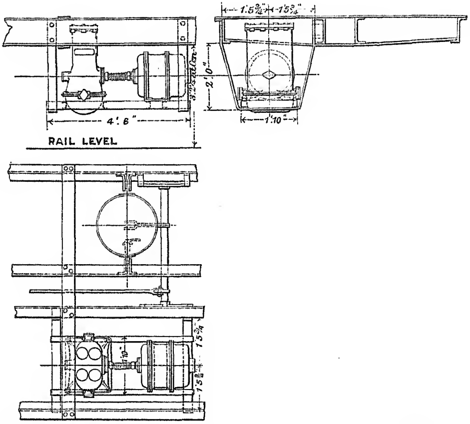


FIG. 230. Arrangement of motor-driven exhauster for the Midland Railway Co.'s electric stock. (Vacuum Brake Company.)

There are two alternative methods which are recommended by the Vacuum Brake Company, one of which is applicable to electric trains in which all the cars are fitted up on the same system, and the other to trains which contain rolling stock in general use on a steam railway and fitted with the ordinary vacuum brake fittings.

The first method consists in fitting the trains with two train pipes, one of which is the ordinary train pipe for applying the brakes, and the other a special train pipe by means of which the two ends of the brake

cylinder, *i.e.* above and below the brake piston, are put into communication. This serves to equalise the two pressures in the cylinders, and releases the brakes; the vacuum is, of course, lowered thereby, but is fairly soon restored by means of the motor driven exhauster.

The other method contains only a single train pipe, and is therefore applicable to trains made up of mixed rolling stock. It consists in supplying on the electric locomotive or on each motor coach two motor driven exhausters, one of which is driven at half-speed continuously for the purpose of maintaining the vacuum; after an application of the brakes both exhausters are run at full speed so as to utilise the full capacity of the pumps and restore the vacuum within a few seconds. This arrangement has the further advantage of duplication, so that if one of the pumps is disabled from any cause the other is capable of working the brakes, though at a reduced speed. Duplicate pumps however are not essential, and a single large one may be used, running normally at a quarter speed, and at full speed after an application of the brakes.

Figure 230 shews the general arrangement of the motor driven exhauster which is being supplied by the Vacuum Brake Company to the Midland Railway Company for the Heysham-Morecambe electrification. The exhauster is driven by its own motor through a flexible coupling, and the set is mounted underneath the coach body, being suspended from the steel girders of the underframe. To prevent damage to the valves from dust it is advisable to close in the exhausters and their motors with a sheet steel case, and to provide for access to the valves from the interior of the coach.

In the case of locomotives, as for example on the Metropolitan Railway, the exhausters would be put in the locomotive cab, and in that case would not require to be enclosed.

CHAPTER 16.

ROLLING STOCK FOR ELECTRIC RAILWAYS, CAR BODIES, UNDERFRAMES, TRUCKS AND LOCOMOTIVES.

Car bodies for electric railways. In most details car bodies for electric railways follow the practice in vogue on steam railways. Certain modifications have, however, been made to meet the requirements of those railways in which the space available for the rolling stock is very much restricted. This is especially the case in "tube" railways, in which it is essential that the diameter of the tube should be kept as small as possible.

It is the general custom in steam railways to arrange the car body on the trucks so that the wheels clear the under surface of the floor of the car by a small distance. The wheels being generally about 40 to 43 inches in diameter and the car body from 8 feet to 8 feet 9 inches from floor to roof, it is obvious that the total height from rail level to top of roof may be as much as 12 feet 6 inches. The inside diameter of the tunnel in the Central London Railway is 11 feet 6 inches; that of the tunnels of the Underground Electric Railways Company of London is 11 feet $8\frac{1}{4}$ inches. It is obvious therefore that the normal rolling stock of steam railways could not be used in such tunnels.

The chief difference in the construction of special cars for these railways lies in the arrangement of the wheels of the trailer (or non-motor) bogies in relation to the floors. The seats at the two ends of the cars, which are not divided into compartments, are arranged longitudinally against the sides of the car, and the structure under these seats is cut away so as to leave room for the upper parts of the wheels. By this construction the floor level in the case of the Central London Railway is 21 inches above the rail level*.

This type of construction is naturally only possible with non-motor bogies. Where motors are mounted on the bogies it is necessary to

* For a full description and illustrations of the rolling stock on the Central London Railway see *Traction and Transmission*, volumes 7 and 8, paper by Messrs Parshall, Hobart and Casson.

raise the floor level; and this is done in the London "tube" railways of small diameter at each end of the train, the two raised parts being reserved for the driver's compartments.

All steel cars. The introduction of tube railways, and accidents therein due to fire, have brought about another innovation of car building, viz. all steel cars. In such cars the whole framework is made of steel, only a very small amount of wood being inserted for window framing, &c., and being rendered non-inflammable before insertion*.

Not only is the car rendered entirely fireproof by this means but the weight is considerably reduced, as may be seen from the following comparison†.

		Metropolitan District Rly. wooden cars	Great Northern Piccadilly and Brompton Rly. steel cars
Length over body		35′ 8″	41′ 8½″
Length over platforms		49′ 9½″	49′ 9½″
Width over end posts		8′ 9″	8′ 8″
Extreme width		8′ 10½″	8′ 9″
Height from floor to roof		8′ 5″	7′ 6″
Height from rail to top		12′ 3¼″	9′ 5⅜″
Wheel base		6′ 6″	5′ 0″
Truck centres		33′ 10½″	33′ 0″
Diameter of wheels	motor	3′ 0″	2′ 6″
	trailer	2′ 6″	
Seating capacity		52	54
Weight		47600 lbs.	35550 lbs.
Weight per passenger seated		918 „	657 „

The underframe for electric railway stock. Rolling stock for electric railways follows as far as possible the standard practice for steam railways. One point of difference arises in some cases in that the weight of the electric stock is considerably in excess of the corresponding coaches on a steam railway, more particularly in the case of motor coaches. The chief item of weight due to the electrical equipment, viz. the motors, is borne by the bogies, but there are several other items which are supported entirely by the underframe. These items include the rheostat, the contactors, reverser, etc., and also the motor compressor and the several reservoirs. For single phase railways the step-down transformer adds considerably to the weight to be supported by the underframe.

It may be, therefore, that the standard underframe may need modification in one way or another to meet the requirements of the

* For full description and drawings of the steel cars for the New York Rapid Transit Subway see *Engineering*, April 21, 1905.

† From *The Electrician*, Dec. 29, 1905.

electrical equipment. An interesting example of an underframe for electric rolling stock is that of the Midland Railway Company's electric motor coach for the Heysham to Morecambe single phase line. In this case the underframe has to support, in addition to the coach body, one transformer weighing about 3 tons, a high tension switch with accessories about $\frac{1}{2}$ ton, a set of contactors weighing about 1 ton, high tension and low tension wiring, and two motor driven exhausters.

This underframe is shewn in figure 231*, and consists of the following parts:—the "solebars" which run the whole length of the coach along both sides are of Z steel $9'' \times 3\frac{1}{2}'' \times \frac{1}{2}''$, and are trussed in the usual way with truss rods as shewn in the drawing; at the ends of the coach the solebars are joined across by two "headstocks" which are wooden beams backed with steel plates, and carry the buffers and the draw-gear. Down the centre from one bogie pin to the other are two steel channels called "longitudinals" consisting of $10'' \times 4'' \times \frac{1}{2}''$ channel steel, the two longitudinals being back to back, and each 6″ from the centre line. The solebars and the longitudinals are joined up together into a framework by "cross bars"; at the left hand end of the drawing, which represents the normal construction, the cross bars A and B which transmit the thrust from the bogie to the solebars are of channel steel $10'' \times 4'' \times \frac{1}{2}''$; these bars carry the bogie centre and also the rubbing plates which bear upon the bolster. The solebars and longitudinals are also tied together in four places by two "middle cross bars" and two "intermediate cross bars." Between the bogie centre and the headstock are two "long diagonals" consisting of angle steel $9'' \times 4'' \times \frac{1}{2}''$; these diagonals help to brace the whole frame, and more particularly the end.

It is usual with ordinary stock to brace the whole frame with several pairs of diagonal plates, crossing each other at right angles, but in this case these have been omitted for the better accommodation of the electrical apparatus. The end of the underframe shewn to the right in the figure is specially modified to suit the motor bogie. The chief requirement is the space necessary for the motors themselves; the wheels project upwards into the underframe to within an inch or two of the coach floor, with just enough clearance to prevent actual contact allowing for the maximum deflection of the springs. The tops of the motors are not quite so high as the tops of the wheel flanges, but project into the underframe; it is therefore necessary to make special provision for them. For this purpose the longitudinals over the

* This drawing was given to the authors, with permission to publish it, by Mr D. Bain, the Carriage and Wagon Superintendent of the Midland Railway. The authors wish to express their thanks to Mr Bain for this interesting information.

motors are only 4″ deep instead of 10″, and the greater part of the thrust from the bogie is transmitted to the full-sized longitudinals by means of the solebars and the special cross bar C. The diagonals at this end are also modified for the same reason, and are quite short, connecting cross bar D with the headstock.

Trucks for electric railway rolling stock. The trucks used on electric railways are almost always of the bogie type, those on which motors are mounted being specially adapted for the purpose. Such trucks are of course well known, but a description may be useful to those who are not familiar with their construction.

As an illustration the motor bogie constructed by the Leeds Steel Forge Co. for the North Eastern Railway may be taken. The details of this are shewn in figure 232, which contains four views, the side elevation and section, the plan, the end elevation and section, and the half-section through the centre.

The car body with its underframe carries the centre A and the side rubbing plates. This centre rests with a spherical seating on the centre plate B, bolted to a transverse beam C called the "bolster," and the two centres are kept concentric by means of the bogie pin or king pin D. The bolster carries at each end a steel plate E called a "side bearer" on which the rubbing plates on the underframe of the coach press. The bolster itself consists of a pressed steel channel $13\frac{5}{16}''$ wide by $\frac{13}{32}''$ thick, 9″ deep in the centre and tapering to $5\frac{1}{2}''$ at the ends. Inside the channel at each end is a block of teak F faced with a steel plate, and these steel plates rest on the helical bolster springs (not shewn in the drawing).

The bolster is situated in the centre of the bogie, and is maintained there by means of the cross bars or "transoms" G. The bogie frame consists of the two "side frames" H and the "end cross bars" or "headstocks" I together with the transoms. The latter serve for three purposes: (1) to stiffen the frame and brace it square by means of the "gusset plates" J, (2) to act as guides for the bolster, and (3) to provide suspensions for the bolster springs. The whole frame including the transoms is made of pressed steel, as shewn in the drawing, and contains the usual provision for the hornblocks and axle boxes. The bolster can move vertically between the transoms, special bearing surfaces K being provided at both ends. A small amount of end play is permitted, being in this case $\frac{3}{4}''$ each way from a central position. Close to each end of each transom is a "swing link" L pivoted to the transom by a $1\frac{1}{2}''$ pin. At each end the two swing links carry a cross bar M upon which rests the "spring beam" N. This spring beam is of hard wood, faced at both ends with steel facings P, which carry the lower members of the bolster springs.

The axle boxes slide in the hornblocks in the usual way, and carry the truck frame by means of semi-elliptical bearing springs (not shewn in the drawing).

The arrangement of the brakes is of course slightly different from that on a fixed axle truck, owing to the relative movement between the coach body and the truck due to the swivelling of the bogie round its centre. On ordinary railway rolling stock hand brakes are not necessary, but each bogie is braked by means of a brake cylinder placed as near it as possible. The bogie contains its own brake rigging, including brake blocks pivoted to the frame by links, brake rods and equalising levers, and the chief modification consists mainly in connecting this brake rigging with the brake piston so that the swivelling of the bogie does not interfere with its proper operation. This is effected in various ways, one method being to provide a roller bearing between the fixed brake rod and the beam on the bogie; the latter is curved with a radius from the centre of the bogie so that as the bogie swings the tension on the brake rigging is not affected. An example of this may be seen in figure 233, which represents the motor bogie made for the Metropolitan Railway by the Leeds Forge Co. In the figure AA are the four brake blocks, pivoted on the levers B and C. The lever B swings from the pivot P carried by the truck frame, there being three possible positions for the pivot so that the wear of the brake shoes can be taken up. The bottom end of the lever B is pivoted to the equalising bar D and connected thereby to the bottom of the lever C. This lever carries the corresponding brake block on the other wheel, the block and the lever being hung together by the swing link E. The upper end of the lever C is pivoted to the brake rod F, which is divided in passing the wheel, and at its other end is connected to the beam G. This beam is guided by means of rollers between the fixed guides H, and on its inner edge is curved with a radius equal to the distance from the bogie centre. The brake rod K terminates in a fork with a roller bearing on the inner side of the beam G; when a tension is applied to the brake rod it pulls on the beam, and hence on to the top of the levers C. These levers turn at first round their bottom pivots and apply the brake blocks to the wheels; then they turn about the pivots on the brake blocks and apply pressure to the equalising bars, and so to the levers B and the brake blocks on the other wheels.

Another point of interest about this arrangement is that the brake rigging is kept to the sides, leaving room for the motors in the centre. This of course is essential for motor bogies. The arrangement described above is only one of many; in other cases the brake blocks are outside the wheels instead of between them, but the general principle of levers

remains much the same. In many cases the necessity of supporting the motors prevents the brake blocks being placed between the wheels, otherwise there would be no room for the motor suspension beams and springs. In figure 233 the type of suspension known as the Baldwin-Westinghouse method was employed (see below), which does not interfere with the inner brake rigging.

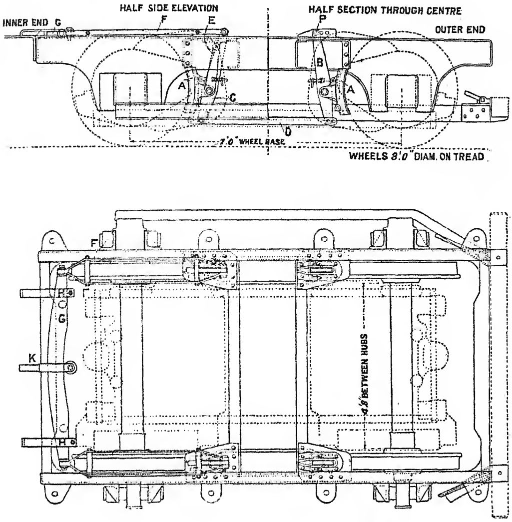


FIG. 233. The brake rigging on the motor bogie for the Metropolitan Railway Company. (Leeds Steel Forge Company.)

Other railway trucks. The bogie truck described above is typical of the general practice in this country. Other forms are in use, however, though not to any great extent.

The six-wheel bogie is sometimes used on the greater railways for special coaches, such as dining cars and sleeping cars. It is in reality an extension of the four-wheel bogie and is very similar. It contains three axles, and between each pair of axles is a bolster of the same type as is used on a four-wheel bogie; the two bolsters are

connected together by a broad steel plate bridging the central axle, in the centre of which is the swivelling bearing. Each of the two bolsters carries a pair of side bearers, which are of course radial instead of being at right angles to the centre line of the bolster. The wheel base is generally about 12 feet to 13 feet, giving 6 feet to 6 feet 6 inches between adjacent axle centres. So far as the authors are aware, bogies of this type have not been used for carrying motors.

The six-wheel truck. Six-wheel trucks have, however, been employed for electric motors, viz. in the high speed experiments on the Berlin-Zossen line. In this case, however, there were no bolsters or bolster springs, and the connection between the truck frame and the car body did not allow of any relative vertical movement. The truck as a whole could swivel about the centre, and there was also a small allowance for lateral horizontal movement between the centre on the car body and the truck, powerful springs being provided to restore the pivot to a central position as soon as the need for lateral movement ceased.

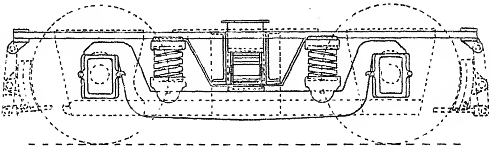


FIG. 234. Master car builder's bogie truck with equaliser bars.

The master car builder's truck. This truck, which is generally used in the United States, differs in many details from the standard bogie in use in this country. Its chief characteristic is the method of spring suspension of the truck frame upon the axle boxes. The axle boxes slide in the hornblocks in the ordinary way, but instead of carrying bearing springs the two axle boxes on each side support an "equalizer bar," which is a U-shaped beam or pair of beams, the ends resting upon the tops of the axle boxes, and the intermediate part carrying the helical springs upon which the truck frame rests. There are, of course, other points of difference, such as the design of the axle boxes and hornblocks to accommodate the equalizer bars, also the frame of the truck is built up of steel bars bolted together, instead of pressed steel plates; but the general arrangement of the centre bearings, the bolster and bolster springs and the transoms, does not differ much from that described above. This type of truck is illustrated in figure 234.

Methods of suspending the motors. The suspension of the motors has already been referred to in previous chapters, and the methods described therein are generally adopted for electric railways; there are, however, several other types which may be noticed.

Nose suspension. This type is the most usual both for tramways and for railways, and consists in supporting the motor on one side by means of bearings on the driving axle, the bearing casings being either cast on or bolted to the motor case; on the other side the motor case has cast on it two lugs which rest on a motor suspension beam, this beam being bolted to the motor frame, and extending transversely across to the truck, the ends resting on springs carried by the truck frame. This type of suspension has already been illustrated in chapter 5 (see figure 51). In another form the transverse motor suspension beam is eliminated and the lugs on the motor case rest directly on helical springs which are carried by a cross bar bolted up to the transom.

Centre of gravity nose suspension. This type is simply a modification of that mentioned above, the motor suspension beam which stretches across the truck being bent round at each end so that the points at which it rests on the springs may be in a vertical plane through the centre of gravity of the motor. The main feature of this type is that the whole of the weight of the motor rests on the suspending springs and not at all on the car axle; it is claimed that this property leads to much less wear and tear of the track than is usual with the ordinary type of nose suspension.

The Baldwin-Westinghouse cradle suspension. In this method a pair of motors is mounted on a bogie by means of a cradle which is itself spring suspended from the bogie axles. The general principle of the method is shewn in the diagram in figure 235, and is also illustrated in figure 233 where the motors are shewn in dotted lines.

In the diagram in figure 235 the motors and the cradle are shewn in full lines and the wheels in dotted lines. The motors MM are hinged to the axles by means of axle bearings in the ordinary way. Each motor casing has a projection midway between the axle bearings on which rests a powerful helical spring S; from the top of this spring is hung by a bolt a transverse beam A which forms one end of a rectangular frame or cradle. The motors are fitted with forked projections $P_1 P_2$ which rest on the side beams B of the cradle. These forked projections are immediately under the motor bearing at the pinion end, and under the motor body at the commutator end. This arrangement has the advantage that the whole of the bogie frame can

be lifted up from the two axles, leaving the motors free for examination or dismounting.

Methods of mounting direct connected motors on bogies and locomotives. Suspensions for direct connected motors vary according to the construction of the motor. The simplest is probably that in which there is no spring suspension at all, as for example on the Central London Railway locomotives. In this case the motor armatures are built on the driving axles; these axles work in axle boxes which are carried by the truck frame, there being no bearing springs whatever. The motor body is mounted rigidly on the truck frame, and the locomotive body is supported on the two trucks in the

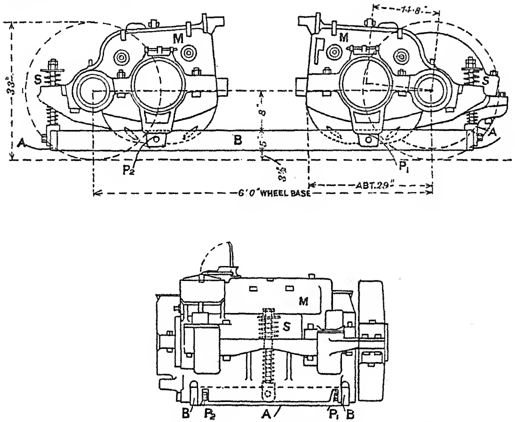


FIG. 235. Baldwin-Westinghouse cradle suspension for motors.

usual way by bolsters and bolster springs. As there are no bearing springs there is no relative motion between the armature and the magnets of the motor; there is therefore no necessity for any motor bearings, and the case occupies practically the whole space between the wheels. This arrangement naturally is advantageous as far as the motor is concerned, but it has drawbacks due to the absence of all spring between the motors and the track; the wear and tear on the rails is very severe, and conversely the shocks transmitted to the motor may easily damage the insulation and possibly the commutator.

If it is decided to use spring suspension for the direct coupled motors there are several alternatives. The most obvious method is to build the motor on a hollow shaft, through the centre of which runs the driving axle. This requires a flexible coupling between the motor armature and the driving axle. An example of this has already been referred to in a previous chapter (page 250), viz. the suspension of the three-phase motors on the motor coaches of the Valtellina Railway.

Another type of spring coupling for motors built on hollow shafts has recently been brought forward by the Westinghouse Company, and consists in a special construction of the driving wheel. This method is illustrated in figures 236 and 237, the former of which shews

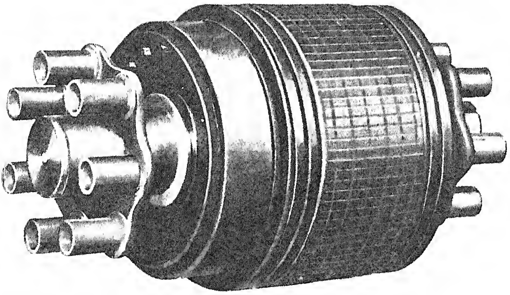


FIG. 236. Westinghouse elastic coupling for direct drive motors. Armature.

the armature with a spider mounted on the end of the armature shaft, and the latter shews a complete motor with a pair of driving wheels. As will be seen from these illustrations there are in the spokes of the driving wheels a number of sockets into which the projections of the armature spider fit. These projections are smaller than the socket holes, and in these socket holes there are spiral springs as shewn in the diagram in figure 238. These springs permit a movement of the armature relative to the driving axle of $\frac{3}{8}$ of an inch in any direction. A small amount of end play is also provided for by the helical spring pressing against the end of the spider projection. The whole weight of the motor, including armature and field magnets, is carried on springs from the truck frame, so that normally there is no stress in the coupling springs. This type of

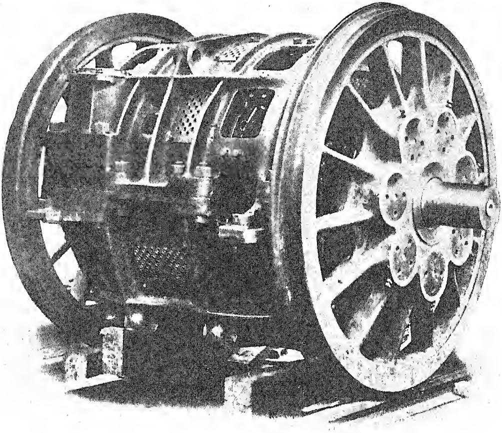


Fig. 237. Westinghouse elastic coupling for direct drive motors. Complete motor with pair of driving wheels.

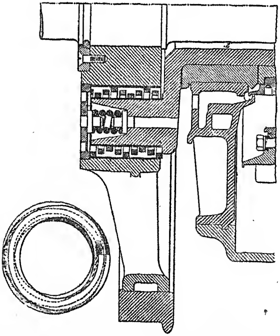


Fig. 238. Arrangement of springs in elastic coupling for direct drive motors. (Westinghouse.)

spring coupling has the great advantage that perfect flexibility is secured, and at the same time very little room is required by the coupling so that almost all the space between the wheels is available for the motor. This method is being adopted on the locomotives for the New York, New Haven and Hartford Railway.

An alternative method, in which provision is made for relative movement between the armature and the field magnets, has already been referred to in a previous chapter (page 251).

1904 locomotives on the Valtellina Railway. Another type of motor suspension has been adopted in the 1904 locomotives for the Valtellina Railway, manufactured by Messrs Ganz and Co. The general scheme of the underframe of this locomotive is shewn in the diagram in figure 239. There are five axles, the three inner ones being driving axles and the two outer ones being pony axles. Each of the latter is connected up to the nearest driving axle by means of a swivelling truck frame, the side frames of which rest upon the axle boxes of the driving wheels, so that there are two bogies similar to maximum traction trucks, each containing one radial axle and one fixed driving axle, together with one fixed axle in the centre. The three driving axles work in axle boxes carried on the locomotive frame by hornblocks in the ordinary way and are connected together by coupling rods on both sides of the locomotive, pivoted on crank pins on the driving wheels. Each of the two main motors is suspended by four links through helical springs from the locomotive frame, and is free to move up and down through a small distance, being guided by hornblocks bolted to the side frames. In these hornblocks are axle boxes in which revolve the motor shafts, and the rotors which are keyed to these shafts are kept concentric with their stators by means of inner bearings attached to the motor cases. The shaft of each motor has a crank at both ends, the two cranks being set at right angles to each other and being balanced by heavy counterweights. These cranks are connected in pairs by connecting rods which are also pivoted to the crank pins on the central driving wheels. It is thus obvious that the three driving axles and the two motors must revolve together, so that even if only one motor is working the whole weight on the three driving axles is available for adhesion. The wheel connecting rods are not rigid throughout but are hinged at their attachments to the motor connecting rods where these pivot on the central wheel crank pins. There is also provision for relative vertical movement between these crank pins and the motor connecting rods, so that all the driving wheels carry no more dead weight in this case than in the case of an ordinary steam locomotive.

These various parts are clearly shewn in the diagram, figure 239,

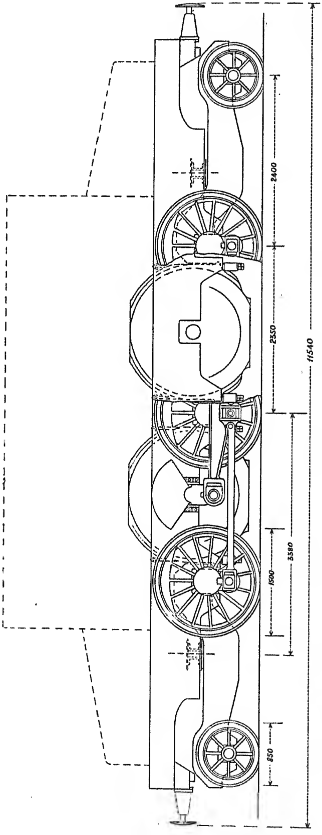


Fig. 239. Diagram of the motor couplings on the 1904 locomotives for the Valtellina Railway. (Ganz & Co.)

which also contains a few of the leading dimensions. This type of motor suspension has several advantages. It enables a gearless motor to be used which may be larger in diameter than the driving wheels to which it is connected; it thereby avoids the limitation on the peripheral speed of the armature or rotor which is inevitable with direct connected motors mounted concentrically with the driving wheels. The motors are accessible for examination and repairs, and can be removed without dismantling. With other types of direct connected motors the armature cannot be removed from the driving axle without first taking off one of the driving wheels.

It should be noticed that the use of side rods is not attended with any troubles due to reciprocating movement as all the moving parts are balanced almost completely by counterweights. The use of locomotives of this type is being extended, similar stock being manufactured for the Simplon Tunnel Railway and for extensions of the electrification on the Italian State Railways.

CHAPTER 17.

THE DIRECT CURRENT RAILWAY TRACK.

The railway track as affected by electrification. The tramway track was considered from two points of view, mechanical and electrical; the railway track must be considered in the same way.

Mechanically, that is to say excluding the bonding, the track for an electric railway differs very little from that for a steam railway, and it is proposed to touch upon the points of difference only. For information upon the subject which is common to electric and steam railways the reader must refer to the proper sources.

In general, the chief difference lies in the character of the rolling stock, and more particularly in the substitution of motor cars or electric locomotives for steam locomotives and passenger coaches. This substitution makes itself felt in the following ways.

(1) The elimination of the reciprocating action of the steam locomotive.

(2) In most cases, more particularly with motor coach trains, a diminution of the maximum weight per axle.

(3) In most cases, an increase in the number of driving wheels.

(4) In most cases, an increase in the non-spring-borne load on the axles.

These four results of electrification to a certain extent tend to counterbalance one another. The elimination of the reciprocating action is in all probability a clear gain; it has been estimated by various engineers that a reduction in the cost of maintenance of track of 20 to 30 per cent. might be expected. In certain cases this may be fulfilled, more particularly where electric locos with spring-borne motors are substituted for steam locos. In other cases, however, the possible gain might be neutralised by the results following on an increase in the number of driving wheels and in the non-spring-borne load on these wheels. These results would be very marked at points and crossings due to the severe hammering which would occur when running over the gaps. Possibly also the large number of driving wheels may be a drawback, especially as it is the practice to work as near the adhesion

limit as is practicable. A slight amount of slipping may not be very objectionable on a locomotive; but when each train contains 16 driving wheels, the matter may become more serious.

There seems to be no doubt that on some of the Underground Railways in London the wear of the rails has been very much increased by the advent of electrical working. This has been attributed to want of proper care in laying the rails, more particularly in not spreading the rails on sharp curves, or in putting down rails which have not been bent to the proper radius. This, of course, could be remedied; and in any case it must be remembered that the general purpose for which electrical working is introduced is to increase the accommodation by providing a greater train-mileage. This alone is bound to produce its own effect.

The increase in the non-spring-borne load is a very important matter in some cases, particularly in urban railways. The matter was brought into prominence by the householders whose houses were situated along the route of the Central London Railway who complained of considerable annoyance due to vibration. The Board of Trade, recognising the importance of the matter, appointed a committee to investigate the cause of the vibration, with the view to the formulation of regulations to be adhered to by any similar railways which should be constructed in the future.

The report of the committee dealt with the subject of vibrations caused by traffic on railways in general, and laid the responsibility on the minute irregularities in the surfaces of the rails and of the wheels. These irregularities give rise to a vertical oscillatory movement of the wheels as they pass over them and of the load rigidly attached to the wheels. Such vertical oscillations react on the rail and produce vibrations which are transmitted through the rail supports to the surrounding earth. Without going into the matter exhaustively, it will be sufficient to state that the vibration set up is compounded of the vibration of the earth itself with its own periodicity and the vibration forced upon it with a frequency due to the non-spring-borne load and the springiness of the rails. The latter is generally relatively unimportant, and the vibration transmitted through the earth consists of trains of waves of the natural period set up by the forced vibrations communicated from the rails. In exceptional cases resonance will occur, *i.e.* the frequencies of the forced and free vibrations will be identical, and in such cases the resulting vibration will be much greater. As a result it is clear that the forced vibrations must be kept as small as possible, and, in order that this may be so, it is essential that the non-spring-borne load should be reduced to its lowest limit.

For instance, as a rough comparison of the effect of different non-spring-borne loads, the committee gives the following figures for the Central London Railway.

For a gearless locomotive with non-spring-borne weight per axle of 7 tons, vibration 10.

For a geared locomotive with non-spring-borne weight per axle of 2·5 tons, vibration 4.

For a multiple unit train with non-spring-borne weight per axle of 1·75 tons, vibration 1.

The actual ratios are probably accidental but suffice to shew that the determining feature is the non-spring-borne weight per axle.

In his report to the committee Mr A. Mallock states:

"It appears then that objectionable vibrations can certainly be avoided by reducing the non-spring-borne load on each axle to something under two tons in the case of a train running at speeds up to 30 miles an hour and on rails laid in any of the usual ways, and no doubt, at present, this is much the simplest procedure.

"There can be little question, however, that if the surface of the rail could be made nearly smooth or with only very long and gentle irregularities, much heavier non-spring-borne loads might be used without inconvenience, and I think this possibility should not be lost sight of, since if train speeds of 100 miles an hour or more ever become common, it is almost certain that more care will have to be taken in making the surface of the track uniform than is at present found necessary."

For further information on this subject the reader is referred to the report itself* which is of great interest.

Note by the authors on the above.

The non-spring-borne load is a somewhat indefinite term and is taken to mean the dead weight of the wheels and the axle and that part of the weight of the motor which is taken by the axle. This, however, is liable to lead to error; thus it might be imagined that the effect of a geared motor would be nil if the motor were spring suspended at its centre of gravity, for in that case the driving axle would take no part in supporting the motor.

The effect, however, of the combined mass is due to its inertia, and it can be shewn that, provided the spring has a range not un-

* Report of the Committee appointed by the Board of Trade to enquire into the vibration produced by the working of the traffic on the Central London Railway. (Eyre and Spottiswoode, 1902, Report $1\frac{1}{2}d.$, Appendices $2s.\ 6d.$)

usually short, the momentum of the impact on a rail when the axle suddenly acquires a vertical velocity V is

$$mV + MV\frac{k^2}{k^2+y^2},$$

where m is the mass of the axle and the two wheels,

M the mass of the motor and gear case,

Mk^2 moment of inertia of the motor, etc., about a horizontal line through its centre of gravity,

and y the distance between the centre of gravity of the motor and the centre of the driving axle.

It will be observed that this expression is quite independent of the point of application of the spring suspension, *i.e.* does not depend upon the division of the weight of the motor between the spring support and the driving axle.

The term non-spring-borne load should, therefore, be interpreted as

$$\left(m + M\frac{k^2}{k^2+y^2}\right).$$

Electrically considered the track is sometimes used as an uninsulated return, and in such cases the running rails must be bonded just as in electric tramways. The subject of bonding the railway track is not so wide as the bonding of the tramway track, for there is no necessity to consider the question of welded joints. However useful or advantageous such methods may be in the case of tramways, they would be out of place on railways.

The subject of bonding has already been discussed in the chapter on the tramway track; but it should be remarked that on railways the current passing in the conductor rails and the track rails is frequently greater than would be the case on a tramway. For this reason bonding on electric railways is often more ample than on tramways; the bonds may be larger or there may be more of them. As an example, the bonding of the conductor rails on the Metropolitan District Railway as shewn in figure 240 may be quoted.

Position of conductor rails. So far the track has been considered merely from the point of view of the track rails. Considered, however, as including the whole permanent way the introduction of electrical working has in many cases involved the use of extra rails for the special purpose of distributing power to the trains. At first sight it would seem that it would be a simple matter to put down a third rail or even two extra rails which should not in any way interfere with existing conditions. This is quite true so far as the greater portion of the track is concerned, although, even so, the

exact positions of the extra rails require very careful attention. At places, however, where two tracks cross or where one track splits up into two divergent tracks the proper spacing and arrangement of the conductors is a difficult problem.

In devising a system of conductor rails it must be remembered that it is absolutely necessary to adhere to the same arrangement

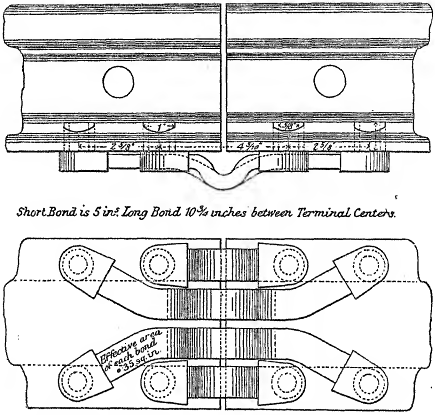


FIG. 240. Type of conductor rail bond at a "fixed joint."

throughout the line. The conditions must, therefore, be laid down first. They will be as follows:

(1) The system must be such that all trains can take current at any part of the line.

(2) Since there are bound to be gaps it is advisable, if possible, to limit them to such a length that they can be bridged by a single car (unless the conditions of the railway are such that no train is ever used with less than two motor cars).

(3) The system must be such that there is a certain minimum clearance between the extra rails and all parts of every kind of rolling stock used on the line (except, of course, the collector shoes).

(4) The position of the extra rails must be such as to cause as little interference as possible with the work of the platelayers.

In order to bridge gaps motor cars are equipped with collector shoes on both bogies. The distance between bogie centres is generally about 42 feet in the case of full-sized passenger coaches (though something less than this for double bogie locomotives). If then collector shoes are mounted on the front and rear bogies the gaps in the line should not exceed 42 feet if the shoes are placed centrally, or say 50 feet if the shoes are placed at the outer ends of the bogies. The actual gaps should be less than these figures by an amount which will allow for the shoes "taking up." Supposing the maximum rise of a shoe (assuming collection from the top of the rail) to be $\frac{3}{4}$ inch and the slope of the approach 1 in 24, the length of each approach will be 1 ft. 6 ins. The actual gaps should therefore not exceed 39 feet or 47 feet.

The exact positions of the rails must be settled by reference to the cross-section of the largest rolling stock or the maximum loading gauge. This loading gauge is a figure which embraces the extreme points of the rolling stock of every kind in use on the line, and does not necessarily represent any actual coach or truck. The gauge varies for different railways and in any particular case should be obtained from the railway in question. A typical example is shewn in figure 55, Vol. II.

In an electric railway in which the power is conveyed to the trains by means of conductor rails there may be one or two extra rails. If one rail only is employed the running rails must be bonded for the return. Figure 241 shews the arrangements of rails which have been adopted on different railways.

It must be noted that if the collector shoes are mounted centrally on the bogie the conductor rails on curves must be displaced from their normal positions towards the centre of the curve, whereas if the shoes are mounted at the extremities of the bogies the conductor rails must be displaced away from the centre of curvature.

At crossings and junctions, more especially where the track is complicated, it is often a matter of considerable difficulty to keep the gaps to such a length that each individual motor coach can bridge them, and in some cases with the conductor rail system in use it is quite impossible. Examples of this occur on the Metropolitan and Metropolitan District Railways in London, where in a few places the gaps are so long that they can only be bridged by joining together the front and rear motor coaches (when the train contains two motor coaches and four trailers) by means of main power cables (or bus lines)

which run from end to end of the train. When, however, a train is split up and consists only of one motor coach and two trailers, it is necessary to coast over these special gaps and the lights are momentarily extinguished.

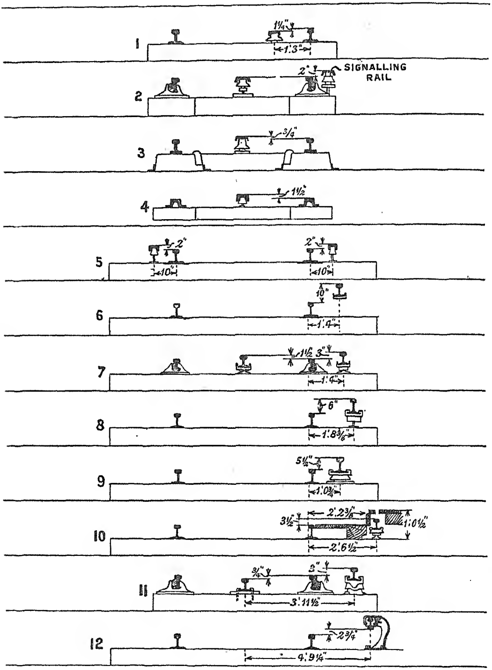


FIG. 241. Arrangement of conductor rails.

1. City and South London Railway.
2. Waterloo and City Railway.
3. Liverpool Overhead Railway.
4. Central London Railway.
5. Great Northern and City Railway.
6. Berlin.
7. Metropolitan and District Railway.
8. Mersey Railway.
9. Paris Metropolitan Railway.
10. Baltimore and Ohio Railway.
11. Lancashire and Yorkshire Railway.
12. New York Central Railway.

As an example of special work, figure 242 shews the disposition of the positive and negative conductor rails at a "scissors" crossing on the Great Northern and City Railway, and in figure 243 a drawing* is given shewing all the details of the track at a "double slip," on which has been inserted conductor rails, the positive rails being on either side of any track and the negative in the centre. It will be seen that the gap in the fourth rail determines the distance over which any single motor coach would have to coast, the gap in this case measuring 59 feet. In the figure, for reasons of space, only half the drawing is shewn; the other half is, however, exactly similar, the whole arrangement being symmetrical about the centre line. This case may be considered as a useful example, but it is by no means an extreme case;

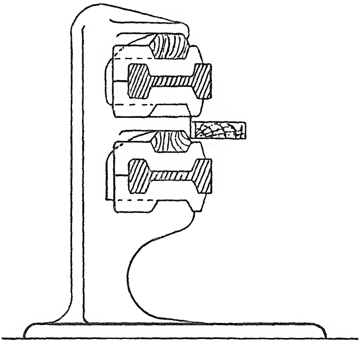


FIG. 244. Proposed arrangement of conductor rails for side collection.

much more difficult places are met with on almost every railway. Each case, however, must be considered individually with the help of actual drawings.

Conductor rail supports. Dealing now with the various methods of supporting the conductor rails, it will be seen from figure 241 that in almost every case the arrangement is adapted for collecting current from the top of the rail. In only one case, viz. that of the New York Central Railway, is this method departed from, and there the collector shoe makes contact on the under surface of the rail. Proposals have been made to collect from the side nearest the train as in figure 244,

* The authors are indebted to Mr Tempest, the Chief Engineer of the South Eastern and Chatham Railway, for the plan of the "double slip."

but so far as the authors are aware these proposals have never been carried out. The arrangement has been criticised on the ground that metallic dust would collect on the board between the rails and would, in time, accumulate sufficiently to facilitate short circuits.

The supports for the conductor rail were at first made of wood. In many ways this is an excellent system, being cheap and serviceable. Experience, however, proved that even if the wood were creosoted or otherwise impregnated the leakage over the surface from the third rail to the ground was prohibitive. Wooden supports were, therefore, abandoned, and various other substances were substituted such as porcelain, vitrified clay, reconstructed granite. Porcelain is undoubtedly the best in some ways, particularly in providing against surface leakage. It is also capable of supporting great pressures, under pure

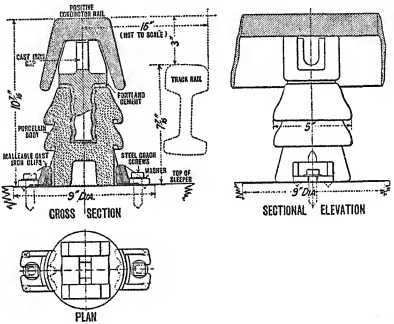


Fig. 245. Insulator for contact rail of inverted channel section.

compression, but it has the disadvantage of being brittle and is easily broken by blows or shocks. If well treated, however, it is perfectly satisfactory, as witness its universal adoption for high tension overhead transmission lines.

The variety of types of support is very great. Probably the simplest is that in which a large porcelain insulator of the well-known telegraph pattern is mounted on an iron stalk bolted to the wooden sleeper, with the conductor rail simply laid on top. In practice, a leather cap is sometimes inserted between the rail and the insulator to minimise shocks, or a cast iron cap is cemented to the porcelain and the rail laid on this cap; an example of this construction occurs on the Hammersmith and City Railway, as shewn in figure 245. This

type of support is, naturally, only possible with rails of an inverted channel section. When rails of other sections are used a malleable iron cap is fastened to the top of the insulator and the rail is either held by the cap or simply supported by it, as in figure 246.

This method is very successful and may be said to have become practically the standard method, with variations to suit various conditions. The leakage over such insulators is very small; thus, for instance, on the Central London Railway the leakage varied from 2 to 6 amperes per section (that is about $1\frac{1}{2}$ miles of double track). It is true that in this case the track is in an underground "tube" and the third rail is not subject to rain storms, but even in the open country the leakage from a properly insulated conductor rail should

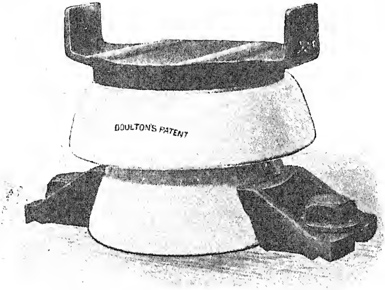


FIG. 246. Insulator for flat-bottomed contact rail.

not under normal circumstances be much greater than the above figures. Under specially bad conditions the leakage may be very great. A case has been quoted* where the leakage from a section of third rail 3 miles long amounted to 150 amperes, which was reduced after 24 hours application of the voltage to the line to 10 or 15 amperes.

Special attention must be paid to all connections with the conductor rails, such as connections with feeder cables, etc. It is obviously useless to take elaborate precautions in respect to the supports, if short exposed cable ends provide an easy path for leakage direct to the earth.

Supports must be capable of standing considerable pressures. The article already quoted* states that for moderate currents up to

* *Street Railway Journal*, July, 1902.

500 amperes a pressure of 15 to 25 lbs. is sufficient; whereas for 1200 or 1500 amperes the shoe may become red hot with a pressure of 50 or 60 lbs. and even 125 to 150 lbs. is not too much.

The supports are always mounted on the same sleepers which carry the running rails or on extensions of the sleepers. In this way the relative positions of the conductor rails and the running rails are maintained practically invariable.

A very important point in the design of conductor rail supports is the provision of suitable protection. This protection is needed for two reasons, first for the platelayers and other people working on the line and, secondly, for the conductor rails themselves against the danger of accidental short circuits due to dropping crowbars, etc. In many cases it is considered unnecessary to put up any protection except in stations and shunting yards; that is to say, in the open country the platelayers must abide by their own accidents. The policy has, however, led to several fatalities where people have strayed on to the

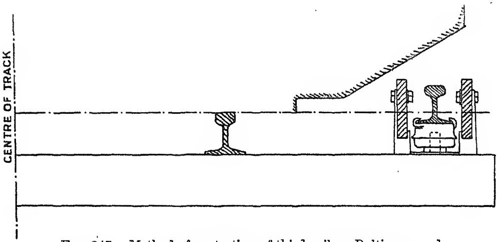


FIG. 247. Method of protection of third rail on Baltimore and Ohio Railway outside stations.

line, and it is strongly advisable that some steps should be taken to prevent such accidents either by protecting the conductor rails or by making it impossible for the public and especially children to stray on to the line.

Protection in most cases consists of wooden boards, which are erected either on one side of the rail or on both sides or above it. Although ample protection is advisable in stations, level crossings and yards, anything elaborate is quite inadmissible in the open from reasons of cost. The illustrations of the third rail on the Baltimore and Ohio railway in figure 241 shews the arrangement of wooden boards in Mount Royal station. The protection in this case is very complete, but the expense of erecting such a structure all along the line would be prohibitive. Outside the station the structure is reduced to two

vertical boards as in figure 247*. This arrangement is very similar to that adopted by all the main line railway companies in England, except that the boards when there is one on each side are to be 8 ins. apart.

The arrangement recently adopted by the New York Central Railway is worth mentioning especially as it is a distinct departure from standard practice, and its consideration brings out several important points in connection with the conductor rail in general.

The support which is indicated in figure 241 is shewn more completely in figure 248†. It will be seen from the latter that the rail is

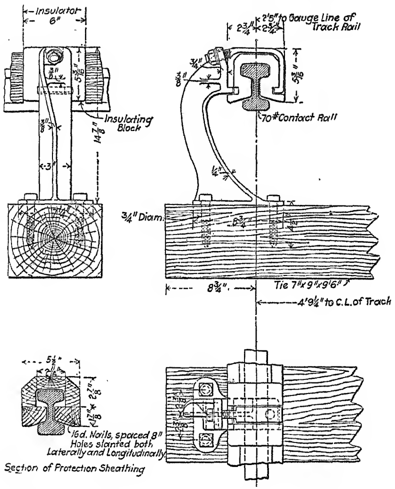


FIG. 248. Third rail protection on New York Central Railway.

supported by being clamped between two blocks of insulating material such as reconstructed granite, vitrified clay, or vibre. Between these supports the rail is covered with a protecting sheathing of wood. The reasons for adopting this design are stated† to be that "the only possibility of reaching the third rail is from below and by an upward movement, and this fact, it is thought, greatly decreases the chance of

* *Street Railway Journal*, March 14, 1903, p. 399.
† *Street Railway Journal*, Sept. 2, 1905, p. 336.

injury from shock. Other advantages which it is claimed are possessed by this arrangement over the ordinary type of third rail are: (1) there is less strain on the insulators as the pressure from the shoe acts against instead of with gravity; (2) the board protection, having a continuous support, is less apt to crack and warp; (3) the rail is more protected from the weather, and hence less liable to corrode; (4) the contact surface is more thoroughly protected from sleet and snow; (5) the construction is self cleaning, and as there is a much greater space between the lower portion of the third rail and the tie, there will be less danger of an accumulation of snow, ice and rubbish, and consequently less leakage." The height of the under surface of the rail has been so adjusted that the same collector shoe is suitable for operation with this system and with a conductor rail arranged for top collection whose upper surface is $3\frac{1}{2}$ ins. above the top of the running rails.

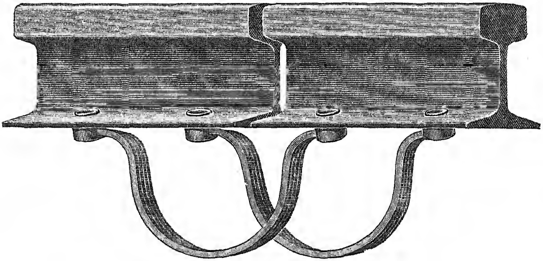


FIG. 249. Type of conductor rail "expansion joint" bond. (Forest City Co.)

Supports are generally spaced about 9 ft. apart, say from 7 ft. 6 ins. to 11 ft. Expansion must be allowed for on all supports except certain selected ones where the rail is anchored. The rail should be divided up into sections and anchored in the middle of each. Sections should be joined by expansion joints and allowance for expansion should be made in the bonding at these places. On the Manhattan Elevated Railway the sections are 300 ft. long, as is also the case on the Liverpool Southport line of the Lancashire and Yorkshire Railway. At all joints, except the expansion joints, ordinary fish plates and bonds are used. Figure 249 shews the bonds used at the expansion joints on the Lancashire and Yorkshire Railway.

Troubles due to the formation of a coating of ice on the conductor

rails are not frequent in this country. In the United States, however, such troubles are not uncommon. Many remedies have been proposed to overcome the difficulties, but practically speaking there are only two courses. The first is simply to scrape the ice off with a suitable scraper mounted a little in advance of the collector shoe. It seems that a steel scraper with cutting edges diagonally across the rail is most efficient. The other course is to project on to the coating of ice a solution of brine, which will produce a fluid mixture which can be brushed off with a suitable brush.

The latter course may involve an unexpected result, as has occurred on the Paris Metropolitan Railway. On this line there is a short

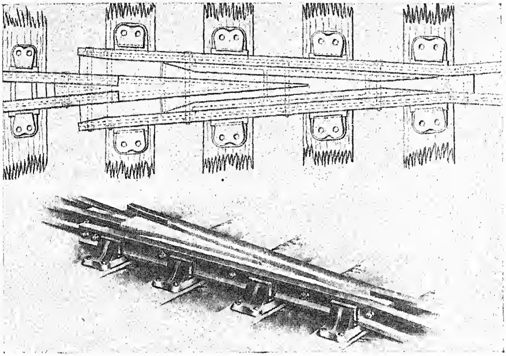


FIG. 250. Manganese steel at railway crossing. (Hadfield.)

length of track in the open, and on one occasion after a snowfall an attempt was made to clear the conductor rails with salt. A fluid mixture was produced; but the leakage of current through this mixture was such as to raise its temperature sufficiently to crack some of the porcelain insulators.

Railway points and crossings. It has been pointed out in connection with tramway working how valuable is the use of special steel at points and crossings, and although there is more wear and tear on account of grit and dirt in the case of tramways, the same remarks apply to railways. The *Street Railway Journal*, Vol. 24, p. 914, calls attention to the use of Manganese steel, and mentions

that a frog which was built with 85 lb. rail was installed on March 11, 1900, at the Broad Street Terminal, Philadelphia, and remained in continuous service until April 27, 1904, giving a service of four years and forty-seven days, where an ordinary steel frog never lasted more than three months. After fitting new rails to this frog and grinding off the inequalities to a level surface, the frog was re-installed on June 30, 1904, and again put into service. The manganese steel employed was supplied by Wm. Wharton, Jr., and Company. The points need hardly be illustrated as they resemble those ordinarily in use. Figure 250 is an illustration shewing how the rails themselves are bolted to the manganese steel casting in the case of a railway crossing, but recent practice, as in the case of tramways, is to make a solid casting with four rail section extensions to which the rails themselves are fixed by aid of fish plates and bolts.

CHAPTER 18.

CALCULATION OF ENERGY CONSUMPTION AND CHOICE OF MOTORS ON DIRECT CURRENT RAILWAYS.

The resistance to motion of railway trains. Many experiments have been made and much has been written in recent years on the subject of the resistance experienced by trains in motion. The most valuable data, however, have been obtained from the very extensive tests carried out on the Marienfelde-Zossen line near Berlin. Before this several papers had been written, notably by Aspinall* giving an account of experiments on the Lancashire and Yorkshire Railway, and also by MacMahon† who dealt with train resistance in tunnels. Previous to these investigators were many others; but the information was derived principally from steam trains, and was, in consequence, of less value as far as electric traction was concerned.

Summing up the results obtained from these sources, it may be said that the total resistance should be divided into two distinct parts, viz. the resistance due to passage through the air, and the frictional resistance due to the journals and the unevenness of the road bed.

Atmospheric resistance. This item must also be divided into two parts, viz. (1) the resistance due to displacement of the air in front of the train, and (2) the skin friction along the train.

With regard to the first of these two parts the formula given by Aspinall, viz. $\cdot 003V^2$ lb. per square foot, was confirmed by a great many tests over a very wide range by the experiments on the Marienfelde-Zossen line, from which the formula $\cdot 00275V^2$ to $\cdot 0028V^2$ was arrived at.

The second part of the atmospheric resistance is by no means so definite; but fortunately it is less important. It is generally assumed that the skin friction adds a percentage to the atmospheric resistance, varying from 10 to 15 per cent. per coach excluding the leading one.

Thus if A be the square feet in the cross-section of the train

* *Proc. Inst. C. E.* vol. 147.
† See abstract in vol. 43 of *The Electrician*.

supposed uniform, composed of n cars, the total atmospheric resistance will be from

$$\cdot 00275 \text{AV}^2 \{1 + \cdot 1 (n-1)\}$$

to

$$\cdot 003 \text{AV}^2 \{1 + \cdot 15 (n-1)\}.$$

Aspinall, however, prefers to express the skin resistance in terms of the length of the train in feet, and his formula for the total train resistance is

$$\text{R} = 2\cdot 5 + \frac{\text{V}^{\frac{5}{3}}}{50\cdot 8 + \cdot 0278\text{L}} \text{ lbs. per ton,}$$

from 3·5 to 79 miles per hour; where L = length of train in feet, V being speed in miles per hour.

The influence of the shape of the front. The pressure of a wind against a cylindrical or spherical surface is well known to be less than the pressure on a flat surface equal in area to the central cross-section of the cylinder or sphere (or the projected area). From the experiments at Berlin the pressure on a cylindrical surface was found

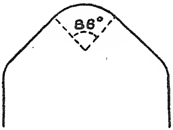


FIG. 251. Profile of front ot train suitable for high speed work.

to be ·7 of the pressure on the projected area. Thus if d be the diameter and l the length of the cylinder the force of the wind on the cylindrical surface will be $\cdot 7dl \times \cdot 003\text{V}^2$.

This fact led to the suggestion that the front surface of the train in cases where high speeds are required should be rounded as in figure 251, the cylindrical front subtending an angle of 86°. With such a shape the experiments proved that the wind pressure on the straight portions of the front would be practically eliminated. The actual proportions of straight and curved parts would have to be settled by structural considerations.

Axle and rolling friction. The second of the parts into which the total resistance is divided consists in reality of several items, such as journal friction, friction of the springs, friction of the flanges of the wheels against the rails. and energy lost in the slight bending of the rails.

Though not strictly correct, it is generally assumed that these items are proportional to the weight of the train, and the friction is expressed in terms of pounds per ton.

The actual value for different speeds is very variable, and depends on many circumstances such as the quality of the road bed and the temperature of the journal lubricant and so on. For instance, under the most favourable circumstances the resistance may be as low as $3\frac{1}{2}$ lbs. per ton, whereas under other conditions, such as exist with contractors' trucks running on a temporary track, the figure may be as high as 70 lbs. per ton.

On railways where a regular service is kept up and the rolling stock is kept in good order the resistance will vary from a minimum of about $3\frac{1}{2}$ to 5 lbs. per ton at about 5 miles an hour up to about 10 to 15 lbs. per ton at 80 miles an hour.

These figures are, of course, rather vague; but it will probably be sufficiently accurate if the lower values are taken for the best track and modern bogie carriages running with well lubricated axles on the straight. For other conditions experience and judgment alone can settle the values to be taken.

Influence of curves. The effect of curves on the rolling friction will depend on the sharpness of the curves. Messrs Asche and Keiley in their book on electric railways give the following method of estimating the increase of resistance due to curvature of the track.

The curvature is reckoned in degrees, a curve of one degree being such that a chord 100 feet long subtends at the centre an angle of 1°. The extra resistance is assumed to be proportional to the curvature as thus defined, and an average as taken in the United States is about ·7 lb. per ton per degree (1 ton = 2240 lbs.).

To find the curvature θ when the radius is given the formula

$$\sin\frac{\theta}{2} = \frac{50}{\text{radius in feet}}$$

may be used.

Other formulae are given by Blondel-Dubois and by Dupuy, viz. $400\text{S}/\text{R}$ kgm. per metric ton, and $\frac{370}{\text{R}-10}$ kgm. per metric ton for standard gauge, where S is the gauge and R the curve radius in metres.

Table 20 gives comparative figures derived from these three formulae, converted into lbs. per English ton.

It must be noted that none of these formulae take account of the wheel base, whereas it is obvious that this must affect the degree of friction between the flanges and the rails. This is probably the reason

why the additional resistance is less according to one of the formulae for a metre gauge than for a standard gauge, the wheel base in the former case being naturally less than in the latter.

TABLE 20. *Tractive resistance due to curvature of track.*

Radius of curve		Additional resistance in lbs. per ton			
In feet	In chains	·7 lb. per ton per degree	Blondel-Dubois (Metre gauge)	Blondel-Dubois Standard gauge	Dupuy
66	1		(44)		
99	$1\frac{1}{2}$	42	(29)	42	40
132	2	31	(22)	32	27
165	$2\frac{1}{2}$	24	(17·5)	25	20
198	3	20	(14·6)	21	16
264	4	15·5	(11)	16	11·5
330	5	12	(8·7)	12·5	9
396	6	10	(7·3)	10·5	7·3
528	8	7·6	(5·5)	7·9	5·5
660	10	6·1	(4·4)	6·3	4·3
990	15	4	(2·9)	4·2	2·8
1320	20	3·1	(2·2)	3·2	2·1
1980	30	2·0	(1·5)	2·1	1·4
3300	50	1·2	(·9)	1·2	·8

Total resistance. Summing up, therefore, the foregoing, and assuming modern bogie coaches running on a level straight portion of an average full-sized railway track, the total resistance to motion will be

$$(4 + \cdot 12\mathrm{V})\,\mathrm{T} + \cdot 0028\mathrm{AV}^2\{1 + \cdot 125\,(n-1)\}\ \text{lb.},$$

from about $3\frac{1}{2}$ to 80 miles per hour, above which speed the axle and rolling friction remain constant.

In this formula

V = speed in miles per hour;
A = cross-sectional area of train, generally about 100 square feet for electrically equipped standard coaches;
n = the number of coaches composing the train;
and T = the weight of the train in tons.

Starting resistance. Aspinall in his paper gives the starting resistance of a modern railway train as 17 lbs. per ton, and the results of similar tests on the Marienfelde-Zossen line gave 12 lbs. per ton.

Resistance in tunnels. The influence of closely fitting tunnels was investigated by McMahon on the City and South London Railway, and the effect seemed very marked. Thus at 20 miles per hour the tractive resistance was found to be 15 lbs. per ton total, and at 25 miles per hour 20 lbs. per ton. It seems probable however that these high values are partly due to the nature of the rolling stock and the track; for investigations* on the Central London Railway where the train fits the tunnel quite as closely the resistance at a speed of from 18 to 22 miles per hour was found to be only 10 lbs. per ton.

Accelerations and retardations. The rates of acceleration and retardation are of great importance in electric traction in cases where it is desired to maintain a high average speed with frequent stops. In such cases it is essential that the train shonld acquire its speed and be brought to rest as quickly as possible, as the starting and stopping periods form a large proportion of the total running time. Further, the economical running of the train is bound up with a high acceleration, as will be explained later.

Acceleration positive or negative is limited, ultimately, by the slipping of the wheels. This limit is expressed by the coefficient of adhesion, that is to say, the greatest pull, expressed as a fraction of the load, which can be exerted at the periphery of the wheel without causing slipping. In practice this coefficient varies greatly according to the state of the rails; if the track, due to moisture or fog, becomes greasy the coefficient may be as low as $\frac{1}{7}$th; with dry rails or rails to which sand has been applied or clean wet rails the coefficient may be as high as $\frac{1}{5}$th or even $\frac{1}{4}$th.

The limits of acceleration and retardation depend in the first place on the state of the rails. In the second place they depend upon the number of wheels to which the acceleration or retarding force is applied. In modern bogie coaches it is customary to apply brake blocks to every wheel; but on the other hand as few axles as possible are driven by electric motors.

In this question it is necessary to distinguish between acceleration and braking, and in the latter to take into account the force that can be applied to the brake blocks, and the coefficient of friction between the brake blocks and the wheels.

Braking. Dealing first with braking, the system almost universally adopted is to press brake blocks against the rims of the wheels. The retardation produced by this means depends, up to the limit when the wheels slip, upon the force applied to the blocks and the coefficient of friction between the brakes and the wheels.

* See articles in *Traction and Transmission*, vol. 8, by Parshall, Hobart and Casson.

Now the coefficient of friction is not a constant but varies primarily with the speed, and secondarily upon other conditions such as the time of application and the surface. In 1878 tests were made by Westinghouse and Galton which resulted in the formula

$$f = \frac{\cdot 326}{1 + \cdot 0353\mathsf{V}}, \text{ where } \mathsf{V} = \text{miles per hour;}$$

for instance, at 5 miles per hour $f = \cdot 278$,
at 25 miles per hour $f = \cdot 173$,
at 50 miles per hour $f = \cdot 118$.

Similar tests* were taken on the Marienfelde-Zossen line in 1902, with results as follows:

at 12·5 miles per hour $f = \cdot 17$,
at 37·5 miles per hour $f = \cdot 064$,
at 62·5 miles per hour $f = \cdot 042$.

The two sets of results are widely different, but in both the decrease of the coefficient as the speed rises is clearly brought out.

Now when it is a question of running a train at a high average speed with frequent stops it is obviously advantageous to bring the train to rest as quickly as is practicable. With a given limit to the retardation it is therefore necessary in order to effect the quickest stop to keep the retardation constant. From the above figures it is at once evident that the pressure on the brake blocks must be graduated as the speed varies.

In the Westinghouse system special apparatus has been introduced for this purpose, viz. for releasing gradually the air pressure in the brake cylinders as the train slows down. Many automatic devices have been patented for effecting the same purpose; but they cannot be referred to here. In estimating the cost of electrically equipping a train it is well to bear in mind that if the schedule has been worked out on the basis of constant retardation special provision must be made for obtaining it.

In actual practice when working out a run the retardation should not be taken at more than 3 feet per second per second, although higher values often occur momentarily on most lines. On the other hand it is uneconomical to assume less than about 2 feet per second per second in cases of high speed with frequent stops.

Acceleration. The limits of acceleration in any particular case must be carefully studied. In electrically equipped trains it is seldom necessary to apply motors to every axle, and from the considerations of prime cost the number of axles equipped is as small as possible. The

* See *Street Railway Journal*, August, 1902.

question of how many motors are necessary must therefore be answered by studying the limits of adhesion. In some cases other considerations must be taken into account, for instance the necessity of splitting up the train into several units. Moreover in self-propelling trains it is not generally considered advisable to equip only the last car, that is to say a motor car should always lead. If therefore a train has to be split up into two parts to be worked separately, there should be at least two motor cars in each part, one at each end (unless each part consists of one car). In many cases, however, division of a train is not contemplated, and then, subject to there being a front and rear motor car, the number of axles equipped must be settled primarily by the question of adhesion. In the particular case of tube railways a recent Board of Trade regulation prohibits any motor coaches in the middle of the train. (See Reg. 9, p. 460.)

Considerations which govern the choice of an equipment. For a given service to be performed by an electric train there may be many different ways in which the motive power may be applied; but all ways are not equally productive of good results.

Leaving on one side for the moment the use of locomotives the problem to be solved is what is the best motor to employ; how many of them; shall they be geared or not; if geared, what ratio of gearing is best; what should be the diameter of the driving wheels.

Beginning with the motor, the number required has already been discussed. It was shewn that it depended upon the acceleration required to maintain the schedule and upon the adhesion.

The size of the motor must be such that it will give the necessary tractive force for acceleration, and shall perform the service required of it without overheating.

The question of gearing or no gearing very often settles itself. If gearing is feasible it will be employed, because of the great reduction introduced thereby in the size of the motor, and because of the simplicity with which the motor can be partially spring suspended.

The choice of gearing is determined chiefly by the consideration of the maximum peripheral velocity of the gear wheels. The limit of gear velocity is generally taken at from 2000 to 2500 feet per minute. The lower figure should be adhered to, if possible; but if circumstances require it the higher limit may be taken. For gear velocities above 2000 ft. per minute maximum the wear of the gear wheels becomes an important factor. In case of urgent necessity higher speeds are permissible with forced lubrication. Messrs Siemens and Halske* on their high speed car on the Marienfelde-Zossen line directed a jet

* See *Electrician*, October 17, 1902, p. 1023.

of oil on the contact between the pinion and the spur wheel. With this arrangement a gear velocity of 3540 feet per minute was reached in practice, and velocities up to 5000 feet per minute were successfully tried experimentally. Forced lubrication, however, of gear wheels is certainly inadvisable except under abnormal circumstances.

The gear ratio should not as a rule exceed 5 to 1.

The size of the driving wheels must at least be sufficient to raise the motor clear of the track. On most railway lines in England the motor should under no circumstances come within 5 inches of the rail level, and a margin of 1 or 2 inches should be allowed beyond this for the reduction in the diameter of the driving wheels due to wear and for the motion of the suspending springs. Each particular case, however, must be studied individually, as the 5 inches mentioned above may not be enough owing to the existence of hog back girders or other obstructions between the running rails. Speaking generally, the size of driving wheels should be kept down as much as possible with a view to keeping up the speed of the motors.

Probable weight of a train. Before beginning any calculations as to capacity of motors, etc., it is necessary to know the weight of the train. In general the weight of a train exclusive of its electrical equipment will be given. In preliminary estimates, however, it is often useful to know how much this is likely to be for different circumstances. Table 21 gives weights in a number of cases:

TABLE 21. *Weights of various types of rolling stock.*

Railway	Weight of car loaded, excluding equipment	Seating capacity	Average speed
Central London Rly.	14—16·5 tons	48	14—17 m.p.h.
Hochbahn, Berlin	16 ,,	about 40	18·6 ,,
Waterloo and City Rly.	22·5 ,,	,, 50	18 ,,
Liverpool Overhead Rly.	16 ,,	,, 50	19 ,,
Milan, Varese Rly.	31 ,,	,, 63	up to 56 ,,
Standard main line bogie coach	22—24 ,,	,, 60	
Corridor coach	25—30 ,,		
Dining car or sleeper	35—42 ,,		

From this list it will be seen that it is quite possible to build cars for moderate speeds to weigh 16 tons inclusive of 50 passengers; but such cars would hardly stand the wear and tear of main line traffic at express speeds.

In reckoning the weight of passengers it is sufficiently accurate to allow 16 to the ton. It must be remembered that sometimes there are twice as many passengers in a car as can find seats.

In estimating the weight of an electric train, the weight of the cars, passengers and trucks is either given or must be assumed. To find the total weight it is necessary to estimate the increase due to the equipment.

In the first place motor bogies, at all events for heavy motors, weigh a good deal more than trailer bogies. A trailer bogie may be about 3 to $4\frac{1}{2}$ tons, of which the wheels and axles will amount to $1\frac{1}{2}$ to 2 tons. A bogie suitable for two 100 H.P. motors would weigh from 4 to $5\frac{1}{2}$ tons.

The weight of the motors and all the electrical accessories will depend on the size of the motors.

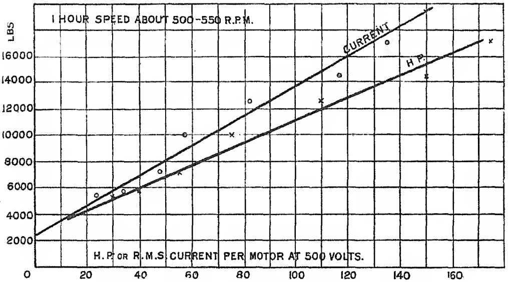


FIG. 252. Relation between weight of two-motor equipment and H.P. or R.M.S. current per motor.

Weight of the electric equipment. Much has already been published with regard to the weights of various railway motors and the accessory controllers and resistances, and in particular the reader is referred to *Die Bahn-Motoren* by Müller and Mattersdorf. As a fairly typical example the figures published for the Westinghouse Company's equipments are plotted in figure 252. As a rough approximation the weight of a 2-motor equipment may be taken as

$$1 + \frac{\text{H.P.}}{25} \text{ tons,}$$

where H.P. represents the horse-power on a one hour rating of each of the motors.

Of course it must be understood that the above only applies to standard 500—600 volt direct current geared motors whose one hour speeds are in the neighbourhood of 500—600 revolutions per minute.

Motor compressor. On electrically driven trains it is necessary to instal a means of providing compressed air for the brakes. This generally consists of a motor compressor on each motor car; and the weight of this must be included in the total weight of the train.

For standard railway coaches such as are used on suburban or main lines, the motor compressor together with the necessary reservoirs, etc., would weigh about 1 ton. This weight is sufficiently accurate for estimating purposes, but for a close calculation more information is desirable and should be obtained from the manufacturers.

Flywheel effect of rotating parts. In addition to the dead weight of the train, the rotational inertia of the wheels and armatures must be taken into account.

The radius of gyration of a car wheel is about ·7 of the radius of the wheel, and the same figure may be taken as approximately true of the armatures.

The effect of rotational inertia may be expressed as an additional mass to be added to the mass of the train.

If n be the number of axles and pairs of wheels,

w the weight of each in tons,

d the diameter of the driving wheels,

r the gear ratio (such as $5:1$),

N the number of motors,

W the weight of each armature,

D the diameter of each armature,

then the additional mass will be

$$(\cdot 7)^2 \times n \times w + \left(\cdot 7 \frac{r\text{D}}{d}\right)^2 \times \text{N} \times \text{W tons.}$$

As a general rule the additional mass will be from 6 to 10 per cent. of the mass of the train.

Application to a particular case. The method of calculating power consumption, etc., is, perhaps, best shewn by working through a typical case.

Suppose it is desired to run a service of trains along a route in which the stations are situated at an average distance apart of 3000 feet, at an average speed of 18 miles an hour including stops of 15 seconds at each station. Each train is to be composed of 6 cars capable of seating 48 passengers. The route is supposed straight and level.

Assume as a first approximation that the train is composed of 2 motor cars and 4 trailers.

Take the weight of each trailer car as 18 tons fully loaded and as a rough guess each motor car 35 tons fully loaded.

Then the total weight will be:

4 trailers at 18 tons	= 72 tons
2 motor cars at 35 tons	= 70 „
	142 „

The next point to assume is the initial acceleration and the maximum speed. The average running time per station is

$$\frac{3000}{18 \times 1{\cdot}466} - 15 = 99 \text{ secs.},$$

and the average speed while running, *i.e.* exclusive of stops, is $\frac{3000}{99}$ ft. per sec., or 30·3 ft. per sec. Assume, therefore, a maximum speed of 45 ft. per sec., and an initial acceleration of 1·5 ft. per sec. per sec.

The maximum acceleration possible will be limited by adhesion, and, if a coefficient of $\frac{1}{5}$th be allowed, it will be due to $\frac{1}{5} \times 70 \times 2240$ lb. tractive force, on the basis of 4 motors per motor car,

$$= 31400 \text{ lb.};$$

deduct from this the tractive resistance, say 10 lbs. per ton, or a total of 1420 lbs., leaving 29980 lbs. for acceleration. Assuming rotational inertia 7 per cent. of the total, the maximum acceleration will be

$$\frac{29980}{142 \times 1{\cdot}07} \times \frac{1}{70} \text{ ft. per sec. per sec.}$$

$$= 2{\cdot}8 \text{ ft. per sec. per sec.}$$

The assumption of 1·5 ft. per sec. per sec. was therefore well within the mark.

The size of the motors must next be considered. If the train is accelerated up to a speed of 30 ft. per sec. before the acceleration begins to fall off the maximum output of the motors will be due to a tractive force of

$$1{\cdot}5 \times 70 \times 142 \times 1{\cdot}07 + 142 \times 10 = 17420 \text{ lbs.}$$

at a speed of 30 ft. per sec., *i.e.* a horse-power of

$$\frac{17420 \times 30}{550} = 950 \text{ H.P.},$$

or about 120 H.P. per motor.

Assume then that each motor coach is equipped with four 100 H.P. motors.

The total weight of the train must now be corrected.

Motor car.	Car body	10 tons,	
	2 motor trucks	8 tons,	
	48 passengers	3 tons,	
	4 motor equipment	10 tons,	
	Motor compressor and brake equipment	1 ton,	
		32 tons.	
Total weight.	2 motor cars at 32 tons		64 tons,
	4 trailer cars at 18 tons		72 tons,
			136 tons.

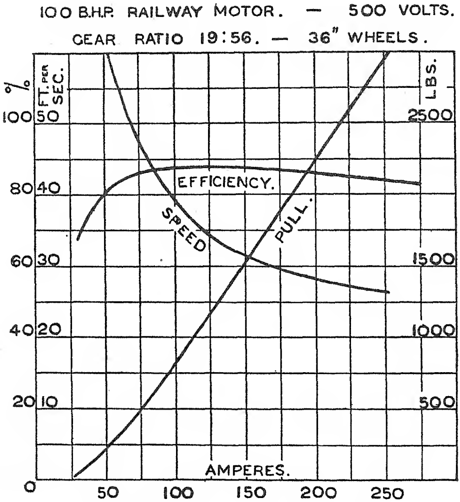


FIG. 253. Performance curves of 100 H.P. motor.

From the list of motors available choose a 100 H.P. motor 500 volts 560 r.p.m. Such a motor would clear the rails by about 7″ with 36″ driving wheels. The distance between centres of motor axle and driving axle would be about 15″. Figure 253 shews the approximate performance of such a motor with a gear ratio of 19 to 56. For this

ratio with 15″ between centres the pinion will have a diameter of 7·6″ and the gear wheel a diameter of 22·4″. When the train velocity reaches 45 ft. per sec., the gear velocity will be

$$\frac{22\cdot4}{36} \times 45 \times 60 \text{ ft. per min.} = 1680 \text{ ft. per min.},$$

which is well within reasonable limits.

The next step is to construct a curve giving the relation between speed and train resistance. It is strongly recommended that this should be done in every case, as a general idea that so many miles per hour corresponds to about so many lbs. per ton independent of the composition of the train is liable to lead to considerable errors when short trains are dealt with.

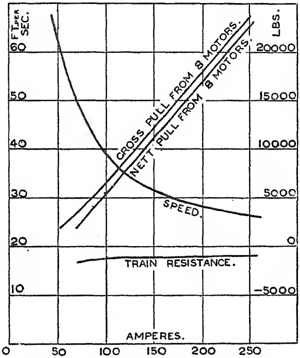


FIG. 254. Curves of tractive resistance of 6-car train and nett pull produced by 8 motors.

In this particular case, assume say 100 square feet cross-section of train; then the resistance will be

$$(4 + \cdot12\text{V})\,136 + \cdot0028 \times 100 \times \text{V}^2\{1 + \cdot125 \times 5\}$$

where V is in miles per hour, or

$$(4 + \cdot082\text{V})\,136 + \cdot0013 \times 100 \times \text{V}^2\{1 + \cdot125 \times 5\}$$

where V is in feet per second.

This curve is plotted in figure 254, and in the same figure is plotted a fresh performance curve giving the nett pull for the 8 motors after

deducting the resistance. This nett pull is, then, the tractive force which produces the acceleration, and the value of the acceleration is found by dividing the nett pull by $(136 \times 1{\cdot}07 \times 70) = 10200$.

Calculation of speed and other curves. The best way of calculating the power consumption is to plot on section paper curves of speed and current against time. It is also convenient to plot at the same time curves of distance and the square of the current per motor against time. The simplest procedure is as follows. Draw the speed curve as a straight line up to the speed at which the motors are in parallel with no resistance in. From this point the acceleration begins to fall off, and the speed curve must be calculated point by point thus:

Current per motor amps.	Speed ft. per sec.	Average nett pull lbs.	Average acceleration ft. per sec.	Interval of time seconds	Distance travelled feet	From start	
						Time	Distance
	0					0	0
185		15300	1·5	19·3	280		
	29					19·3	280
		13750	1·35	1·5	45		
155	31					20·8	325
		10600	1·04	1·9	62		
135	33					22·7	387
		8600	·84	2·4	82		
120	35					25·1	468
		7050	·69	2·9	105		
109	37					28	573
		5900	·58	3·4	130		
100	39					31·4	703
		4900	·48	4·2	166		
93	41					35·6	869
		4150	·41	4·9	206		
87	43					40·5	1074
		3450	·34	5·9	259		
81	45					46·4	1333

The speed and distance curves so found are shewn in figure 255.

Next start from the other end of the run and draw the curve of braking (assumed constant at 2 ft. per sec. per sec. retardation) finishing at 99 seconds; also draw the finish of the distance curve up to 3000 feet at 99 seconds. With the beginning and the end thus plotted out a little trial and error calculation will shew when to start coasting, the retardation being calculated from the train resistance in the same way

as the acceleration is calculated from the nett pull, and when to put on the brakes. These times will be found to be 42·5 seconds and 79 seconds respectively.

The square of the current per motor must then be plotted and integrated up to 42·5 seconds.

The area of this curve is found to be 952000 amp.^{2} secs.

The run is repeated on the average every 114 seconds;

$$\therefore \text{ average value of (current per motor)}^2 = \frac{952000}{114} = 8340;$$

$$\therefore \text{ the R.M.S. current per motor} = \sqrt{8340} = 91{\cdot}3 \text{ amperes.}$$

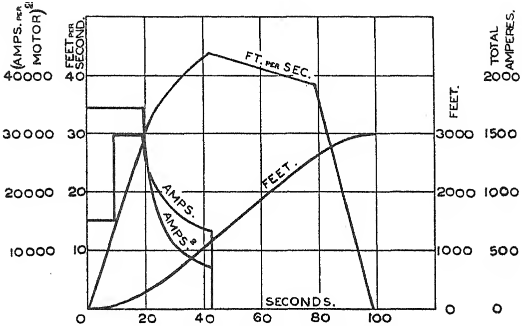


FIG. 255. Speed-time curve for typical run.

In the same way by plotting the current taken by the whole train and integrating, the consumption of energy is calculated. In plotting this curve the first 19·3 seconds must be divided up into two parts corresponding to series and parallel running. The former is a little shorter than the latter and can be calculated as already shewn in chapter 4.

The area of the current curve is found to be 42200 amp. secs. This can be converted into watt hours per ton mile thus:

$$\text{Watt hours per run} = \frac{42200 \times 500}{3600} = 5860 \text{ watt hours.}$$

$$\text{Distance run} = 3000 \text{ feet} = \frac{3000}{5280} \text{ mile} = {\cdot}569 \text{ mile.}$$

$$\therefore \text{ watt hours per ton mile} = \frac{5860}{136 \times {\cdot}569} = 75{\cdot}6.$$

Now a 100 H.P. 500 volt motor such as was chosen for the purposes of calculation will take about 84 amperes as the R.M.S. current without overheating. It is clear, therefore, that eight 100 H.P. motors are insufficient for the service required, and the calculation should be remade with eight 110 H.P. motors.

Analysis of energy consumption. It is strongly recommended that the energy consumption should be analysed as a rough check on the calculation, and in order to obtain some idea of how the energy is being expended.

Thus the total may be divided into four parts:

Energy put into the brakes $= \dfrac{2240 \times 136 \times 1{\cdot}07 \times 38{\cdot}5^2}{2 \times 32}$ ft. lbs.

Energy lost in overcoming tractive resistance;

approximate resistance = 1200 lbs.; energy = 1200×3000 ft. lbs.

Energy lost in the motors and gearing;

say about 17 per cent. of the input or 20 per cent. of the output.

And energy lost in the controlling resistances;

roughly 50 per cent. of the kinetic energy of the train when the controller reaches the final position.

In this case therefore,

Energy put into the brakes $= 7{\cdot}55 \times 10^6$ ft. lbs. = 2840 watt hours,

Energy lost in tractive resistance $= 3{\cdot}6 \times 10^6$ ft. lbs. = 1350 „ „

Energy lost in motors and gearing

$= {\cdot}2 \times (2840 + 1350) =$ 840 „ „

Energy lost in controlling resistances

$$= {\cdot}5 \times \frac{2240 \times 136 \times 1{\cdot}07 \times 29{\cdot}2^2}{2 \times 32} \text{ ft. lbs.}$$

$= 2{\cdot}15 \times 10^6$ ft. lbs. = 810 watt hours.

Total = **5840 watt hours.**

From this analysis it is apparent that the energy lost in the brakes is of the greatest importance, since the energy lost in the tractive resistance is invariable. That is to say, any alteration which will reduce this item will likewise reduce the watt hours per ton mile, provided the alteration is not such as to increase by a greater amount the rheostatic losses.

For instance, in the above case the energy consumption might be reduced by the use of a greater initial acceleration, provided the speed attained at the end of the switching on period is not greater than before. This would enable the distance to be covered with a lower maximum speed, and a less expenditure of energy in the brakes.

Variation of power consumption with initial acceleration. As an example of the influence of the initial acceleration on the energy consumption, the same case has been worked out with an acceleration of 2·4 ft. per sec. per sec.

The analysis of the energy consumption is as follows:

Energy in brakes	2190	watt hours,
Energy in tractive resistance	1490	,, ,,
Motor losses	740	,, ,,
Rheostat losses	890	,, ,,
Total	5310	,, ,,

shewing a saving of 530 watt hours per run.

The diminution in watt hours per ton mile is still more marked, as the weight of the train is increased from 136 tons to 150 tons on account of additional motors.

Other considerations which influence choice of acceleration. Judging solely by the above figures it would appear that the greater the initial acceleration the better. It is necessary, however, to take into account external circumstances. High accelerations require large currents, which probably mean heavy feeders and large sub-stations.

The following comparison will bring out this point:

Distance run, feet	3000	3000
Weight of train, tons	136	150
Acceleration, ft. per sec. per sec.	1·5	2·4
Watt hours per ton mile	75·6	62·5
Average current per train, amps.	370	337
*Max. current per train, amps.	1480	2520

This comparison makes it manifest that, although the energy consumption for the train has been reduced about 10 per cent., the maximum demand is nearly doubled. This would in all probability involve such an increase in the feeding system and the capacity of the sub-stations or generating station as would neutralise the gain obtained from the reduced energy consumption. Beyond this, there is the further consideration that the first cost of the electrical equipment of the train has been increased by approximately 50 per cent.

It is evident, then, that the most favourable manner in which to run the train is a question requiring careful study in each individual case.

Approximate prediction of energy consumption. It is sometimes very convenient to be able to predict roughly for estimating

* The momentary maximum current per train is of course higher in both cases due to the steps of the controller; the currents given in the comparison are the average currents while resistance is being cut out, motors in parallel.

purposes the energy consumption in any particular case. Figure 256* shews a curve which will enable one to find out the watt hours per ton mile without the necessity of going through the calculation.

For instance, find the watt hours per ton mile for a train which has to maintain an average speed of 25 miles per hour including stops of 20 seconds every 4000 feet.

$$\text{The running time} = \frac{4000}{25 \times 1{\cdot}466} - 20 \text{ seconds} = 89 \text{ seconds.}$$

From the curve the watt hours per ton mile will be

$$\cdot 03 \times 4000 = 120.$$

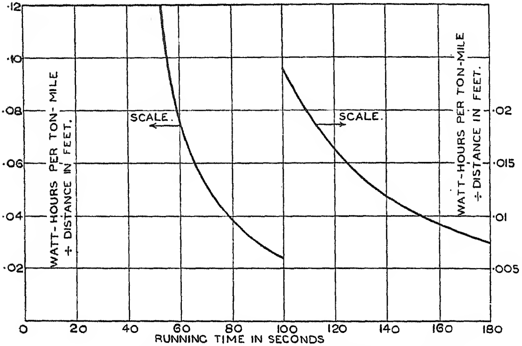


FIG. 256. Curve shewing the relation between watt hours per ton mile, length of run, and running time.

As already explained, the energy consumption of a train is by no means a fixed quantity, and this curve can only be taken as representing average conditions; for any exact work complete calculations should be made.

It is, however, of interest as shewing graphically how the consumption for any given run varies with the time allowed in which to cover the distance.

Thus, in the above case, if instead of 89 seconds, 109 seconds were allowed, the watt hours per ton mile would be only 80 instead of 120, and the average current per train would shew a still greater decrease.

* This curve may be compared with that given by Mr Carter in his paper before the Institute of Electrical Engineers, Jan. 25, 1906. The curve given here was worked out by one of the authors in 1902.

Influence of grades. In performing the calculations for a projected electric railway it is sufficiently accurate for most purposes to assume that the stations are an equal distance apart. Very few lines, however, are altogether level, and it is necessary to consider how the grades should be taken into account. To make the calculation accurately, there is nothing for it but to work through each run with its proper grades.

It is not enough to find the average grade, and work out a run in each direction over the average distance with this average grade. This method takes no account of the position of the grades in relation to the stations. If the stations are placed on the top of two slopes descending on each side, the train will be enabled to start with a greater acceleration than on the level, and will lose less energy in the brakes as the slope itself will produce the retardation. A good example of this is the Central London Railway, in which the grades were specially designed with a view to economy of energy. On the other hand, if the stations are situated at the bottom of two slopes ascending on each side, the consumption of energy will be greater than on the level.

An experienced engineer may be able to say what the effect of any set of grades may be, but in any case it is safer to go through the calculations, and it is often necessary to do so for the purpose of determining the current required at the different points of the line.

Method of calculation when there are grades. A simple modification of the method given above is necessary to take account of grades. Supposing the 3000 feet in the example on p. 374 had been on an up grade of 1 in 100. Then there would be a pull due to gravity of

$$\tfrac{1}{100} \times 136 \times 2240 \text{ lbs.} = 3050 \text{ lbs.},$$

and the calculation will be as follows:

Current per motor	Speed ft. per sec.	Average nett pull	Pull due to grades	Pull for acceleration	Acceleration	Interval of time	Distance	From start: Time	From start: Distance
	0								
185		15300	− 3050	12250	1·2	24·2	350		
	29							24·2	350
		13750	− 3050	10700	1·05	1·9	57		
155	31							26·1	407
		10600	− 3050	7550	·74	2·7	87		
135	33							28·8	494
		8600	− 3050	5550	·545	3·7	125		
120	35							32·5	619

and so on.

Suburban railways. The case of an electric railway considered on p. 374 is fairly typical of the systems already in operation. It is, however, a type of one particular class of railway service, viz. the strictly local service.

Without necessarily including all kinds it may be said that besides the local traffic there are two other kinds, viz. suburban and main line.

Now if the time-table of one of the large railways be studied it will be evident that the suburban traffic consists partly of trains which stop at every station, partly of trains which make no intermediate stops, but chiefly of trains which stop at some of the intermediate stations. If, then, any scheme is taken in hand to electrify the suburban system throughout, the problem of the best means of applying the motive power to the trains presents itself at once.

Obviously there are two broad methods. First, the steam locomotives may be replaced by electric locomotives; second, the steam locomotives may be discarded and motor equipments mounted on the bogies of the passenger coaches.

It would be, of course, absurd to decide off hand in favour of either method. The advantages and disadvantages of each must be studied with great care and with full information before any decision can be arrived at. In a general way the pros and cons can be stated thus:

Locomotives.	Motor cars.
1. Not much improvement as regards shunting at the terminus.	1. Considerable saving of shunting at the terminus.
2. No great increase in the average speed possible.	2. Considerable increase in the average speed made possible.
3. No alteration to existing rolling stock.	3. Alteration to existing rolling stock, possibly the necessity for a large quantity of new stock.

This comparison would seem to indicate that the chief points in favour of electric locomotives as against motor car trains are lower first cost and minimum interference with rolling stock. On the other hand it may be said that there is very little to be gained and a great outlay necessitated by simply replacing steam by electric locomotives. This point, however, is beside the question. Circumstances may force a company to electrify their line, and the question then is, how shall it be electrified. Such a case has occurred in the United States on the New York Central and Hudson River Railroad; and in this case the decision was in favour of electric locomotives.

The question, therefore, is not one which can be answered for all cases without knowing all the circumstances of each case.

Whichever system is finally decided upon the calculations to be made will be very similar. They must be made in precisely the same way as already described. It is interesting, however, to study briefly the difficulties that must be overcome in both methods.

Particular case. It will be very instructive to examine a particular hypothetical case. Take for example some of the suburban lines of the London and South Western Railway. From the published time-table the following information is obtained:

Line from Waterloo to	Distance miles	Number of runs	Average run miles	Average speed, stopping everywhere m.p.h.	Number of intermediate stops on quickest journey	Average speed on quickest journey m.p.h.
Guildford	30	14	2·14	20	3	30
Woking	$24\frac{1}{2}$	12	2·04		0	40·8
Hampton Court	15	9	1·67	19·2	2	32·2
Wimbledon	$8\frac{1}{2}$	8	1·06	18·2	1	23·2
Windsor	$25\frac{1}{2}$	14	1·82	21	3	34·8
Kingston	15	14	1·07	17·3		

Now it is fairly obvious that if the whole system is to be electrified one style of equipment must be adhered to throughout. It is out of the question from the traffic point of view to employ motor cars which will maintain a high average speed on short runs of a mile, and which will be unsuitable for a reasonably high speed on a run of say 15 miles. Similarly it would be a great drawback if several designs of locomotive were necessary. It would certainly be advisable to select the equipments as a compromise, if necessary, between the conditions for short runs and for long runs.

In the first place, then, it is evident that the trains must be able to attain a maximum speed of at least 50 miles per hour, and it would be an advantage to make allowance for a still higher maximum speed.

Now if motor cars be employed with geared motors, this high speed will involve high gear velocity; thus, on the Milan-Varese line the maximum speed is 56 miles per hour, and with 150 H.P. motors geared by 3 : 1 ratio to 41″ wheels the gear velocity is 2640 ft. per minute. Similarly on the Aurora, Elgin and Chicago Railway the maximum speed is 65 miles per hour, and with 125 H.P. motors geared by 1·61 to 1 ratio to 36″ wheels the gear velocity is 2860 ft. per minute. It will be observed that in both these cases the velocity of the gearing is considerably above 2000 ft. per minute.

The alternative to geared motors is gearless motors. The speed of such motors with 36″ wheels at 60 miles per hour would be 560 revs. per minute, which is approximately half the maximum speed of a geared motor. Such a low speed would mean a relatively large and heavy motor with a poor efficiency.

The case of locomotives is, however, more favourable both with gearless motors and with geared motors for the simple reason that the space for the motors is not so restricted.

To make this clear it is best to consider it from the point of view of armature peripheral speed. Take first a motor coach; under existing conditions it is hardly practicable to use driving wheels with a diameter greater than 43 inches. Assuming a normal clearance of 7 inches between the motor and the rails the external diameter of the motor cannot be greater than 29 inches and the armature diameter must be limited to about 20 inches. Hence for a gearless motor the armature peripheral speed corresponding to a train speed of 60 miles per hour will be $\frac{20}{43} \times 60 \times 88$ feet per minute, *i.e.* 2460 feet per minute, whereas with the ordinary geared motor the maximum peripheral speed may be taken as from 5000 to 6000 feet per minute. This difference in speed is very marked, and would be apparent in its influence on the weights and efficiencies of the motors.

Compare the above, now, with the case of a locomotive with gearless motors. The limitations as to the driving wheels are not so narrow for a locomotive, and there is no objection to wheels having a diameter of 60 to 70 inches. Assume a diameter of 65 inches and make the same allowances as before (*i.e.* supposing the motor is multipolar, say 8-polar, and has a field with the same radial dimension as above); then the maximum diameter of the motor is 51 inches, and of the armature is 42 inches. Hence at 60 miles per hour the armature peripheral speed will be $\frac{42}{65} \times 60 \times 88 = 3420$ feet per minute, which compares favourably with the value obtained above.

With geared motors the difference is still greater. For the motor coach with 43 inch driving wheels, a gear velocity limited to 2500 feet per minute, an armature diameter of 20 inches and a distance between motor and axle centres of 16 inches, the peripheral speed corresponding to 60 miles per hour would be 4300 feet per minute; whereas with a 65 inch driving wheel the same gear velocity, an armature diameter of 30 inches and a distance between centres of 22 inches, the peripheral speed of the armature corresponding to 60 miles per hour would be 5700 feet per minute.

It seems, therefore, that for the conditions that would normally be met with in a suburban railway system the choice lies between motor coaches equipped with geared motors and locomotives. The choice of

motor coaches would involve either a high gear velocity or a low motor speed, neither of which is so marked with locomotives.

These considerations, of course, deal only with one aspect of the problem; many other points of view must be included before any just decision can be arrived at.

It may be of interest, however, to note that electric locomotives have been adopted in some cases. On the Metropolitan Railway in London, through passenger trains from Baker Street to Aylesbury are hauled over the electrified portion of the line by electric locomotives. Precisely similar conditions prevail on the New York Central and Hudson River Railroad, and on the New York, New Haven and Hartford Railway. On the latter railway the locomotive will weigh 78 tons, and will be equipped with four gearless motors each of 400 horse-power capacity*, and will be capable of maintaining an average speed of 26 miles per hour with a train of 200 tons stopping every 2·2 miles. For express service it will reach a maximum speed of 60 to 70 miles per hour with a 270 ton train.

Energy consumption in lighting, heating, etc. So far the calculation of energy consumption has been confined to that required for propulsion. Beyond this, however, there are other items which go to make up the total. They are as follows: lighting, heating, control, and compressed air for brakes, etc.

Lighting. This item naturally varies according to circumstances; but the following examples are sufficient to give some idea of what may be allowed.

Manhattan Elevated Railway, per car	30 16 C.P. lamps.
Electric Elevated and Underground Railway, Berlin, per car seating 40 passengers	12 lamps.
Central London Railway, per car seating 48 passengers	10 16 C.P. + 10 8 C.P. lamps.
Waterloo and City Railway, cars seating about 50	11 lamps.

Heating. This also depends on circumstances.

In the Manhattan Elevated Railway each car consumes 12 kw. in heaters. In this country, however, this would probably be excessive, and an allowance of 6 kw. should be sufficient. In the electric trains on the Metropolitan Railway each car is fitted with heaters with three grades, the current being 7, 13 and 20 amperes at 500 to 600 volts.

* For further particulars of these motors see chapter 5, vol. II.

Control. This is a small item in any case.

In the General Electric Company's Type M control, the operating current for a car equipped with two 160 H.P. motors is $2\frac{1}{2}$ amperes at 550 volts. In electro-pneumatic systems the energy required would be considerably less.

Compressed air for brakes, etc. In the case of the Central London Railway* the energy required for the motor compressor amounted to 800 watt hours for a double journey of 11·5 miles, the weight of the train being 150 tons. This is equivalent to an average consumption of ·9 kw. per train. This figure does not include any allowance for compressed air for operating the control.

* *Traction and Transmission*, vol. 8, p. 73.

CHAPTER 19.

FEEDER SYSTEMS FOR DIRECT CURRENT RAILWAYS.

The feeder system for electric railways using direct currents is, necessarily, in many ways similar to that required by electric tramways. As already mentioned, no hard and fast line can be drawn between a tramway and a railway, at least from the electrical standpoint; in the United States there are many interurban railways which are only distinguishable from tramways in that the cars run for longer distances without stopping.

For present purposes it may be sufficient to draw an arbitrary line of division, and treat as railways those systems in which for one reason or another the ordinary overhead construction for trolley wires is unsuitable.

The chief reason for discarding the overhead trolley wire is the employment of currents too great to be carried by the wire or collected from it. With the trolley wires and collectors in general use the limit for collection at a single point may be taken at about 150 amperes.

Beyond the limit so imposed the general practice is to use steel conductor rails supported by special insulators from the sleepers on which the track rails are laid. The general method of support and details of the insulators have already been given (chapter 17, page 357). In this chapter the conductor rails are regarded as part of the feeder system.

Resistance of conductor rails. Before going further into the consideration of the feeder system it will be advisable to examine the question of the resistance of the conductor rails. It has been stated in a previous chapter that the resistance of track rails is generally about 12 times that of copper of the same section. The conductor rails have a different function to perform, and there is obviously an advantage in using higher conductivity steel even at the expense of hardness and durability.

A good deal of information has been published from time to time as to the relation between composition and conductivity, but most of it that concerns conductor rails is included in a paper read by J. A. Capp before the American Institute of Mining Engineers on October 15, 1903 (reported in the *Street Railway Journal*, November 24, 1903, page 775). Quoting from this paper, Table 22 gives a number of samples of rails for various purposes:

TABLE 22. *Resistance and Composition of Steel, at about 20° C.*

Serial number	Specific resistance 10^3	Resistance relative to copper	Percentage composition C	Mn	P	Si	S	Remarks
1	22·72	13·2	·33	1·27	·09	·05	·05	Standard track rails from several makers.
2	20·9	12·12	·17	1·09	·09	·05	·004	
4	19·87	11·55	·20	·95	·10	·08	·05	
7	19·81	11·51	·22	1·08	·10	·05	·06	
11	17·27	10·04	·36	·87	·08	·09	·04	
15	16·95	9·86	·29	·99	·084	·01	·01	
18	16·21	9·42	·28	·65	·083	·06	·05	
21	15·32	8·9	·33	·49	·068	·05	·02	
24	14·73	8·42	·144	·46	·09	·08	tr	Conductor rail on the Aurora, Elgin and Chicago Railway.
25	14·62	8·36	·188	·48	·09	·08	tr	
34	13·31	7·74	·25	·37	·04	·03	·018	
40	13·07	7·6	·28	·42	·022	·04	·008	
45	11·01	6·4	·05	·019	·054	·059	·03	Conductor rail used on the underground electric railways of London.
46	13·8	7·82	·15	·068	·13	·02	·15	Ordinary refined bar iron.
48	13·1	7·41	·16	·074	·12	·027	·10	
49	12·54	7·11	·08	0	·13	·008	·024	Special refined bar iron.
50	11·92	6·76	·17	·027	·074	·022	·077	
51	10·82	6·17	·058	·10	·014	0	·012	Swedish iron.
52	10·80	6·12	·16	·018	·049	·011	·015	Norway iron.
B	11·00	6·44	·03	·036	·065	·016	·14	
SCI	10·35	6 06	·028	tr	·004	·005	·07	

From these and other results it is evident that of the usual impurities, carbon and manganese have the greatest influence. Messrs Barrett, Brown and Hadfield* have found that the increase of resistance due to manganese rises rapidly at first, then more slowly, as the proportion of manganese increases to 7 per cent., after which there is very little further alteration.

A formula for the specific resistance which gives very fair agreement for conductor rails is

$$\text{specific resistance} = 10^3 (10 + 7 [\mathrm{C} + \mathrm{M}n^2]) \text{ at about } 17^\circ \text{ C.},$$

or $$10^{-6} (10 + 7 [\mathrm{C} + \mathrm{M}n^2]) \text{ ohms per cm. per sq. cm.},$$

in which C and Mn are the percentages of carbon and manganese.

The author of the paper quoted above recommends the following composition:

Carbon	not to exceed	0·15	per cent.
Manganese	,,	0·30	,,
Phosphorus	,,	0·06	,,
Sulphur	,,	0·06	,,
Silicon	,,	0·05	,,

as representing a steel with conductivity about $\frac{1}{7{\cdot}5}$ times copper, and being reasonably hard and not too expensive.

Conductor rails in general use. The cross-sections of conductor rails have already been referred to in chapter 17, page 359, but it may be said here that it is usual to employ heavy rails weighing perhaps 90 lbs. a yard or more. On the City and South London Railway much lighter rails are used, but in this case the trains are not so heavy as in the majority of other electric railways.

Consider, then, a conductor rail weighing 90 lbs. per yard; such a rail would have the resistance of 9 square inches of copper multiplied by say 7·5; *i.e.* $\frac{{\cdot}042}{9} \times 7{\cdot}5$ ohms per mile = ·035. This rail could carry a current of 1430 amperes for one mile with a drop of 50 volts. Such a current at 500 volts is equivalent to 715 kw. or say 800 H.P. output. This illustration is sufficient to indicate that there is in general no need for supplementary low tension feeders if sub-stations be distributed along such a line at intervals of 2 or 3 miles.

The low tension feeding system. Of direct current railways in actual operation, the greater number are supplied from sub-stations. A little consideration will shew that the range over which direct currents could be distributed, of the magnitude required for the operation of heavy railway trains, is comparatively small, and when the distances

* *Transactions of the Royal Dublin Society*, vol. 7, series 2, part 4.

exceed two or three miles, considerations of economy in first cost make it imperative to adopt some system of high tension transmission combined with distributed sub-stations. This being so, the question of dividing the line into a number of sections must be treated accordingly.

As far as railways are concerned there is no Board of Trade rule requiring a division every half mile, and the engineer is free to choose the arrangement that is most suitable as far as the traffic and the feeder system are concerned. The provision of sub-stations containing rotating machinery, and therefore requiring the constant presence of an attendant, affords a convenient and simple solution of the problem. The switchboards in the sub-stations, with their line feeder switches, thus take the place of the various feeder automatic circuit breakers usually assembled on the switchboard in the generating station of a tramway system. All sub-stations are, of course, connected to the main power house by telephones.

In general, then, the calculation of the low tension feeder system is confined to the determination of the distances between sub-stations, so that the drop in the conductor rails may be kept within suitable limits. In dealing with the feeder system for electric tramways a set of factors was proposed by which the average current per car should be multiplied in order to obtain the effective maximum current. Such a method is hardly applicable to railways, since the number of distinct units supplied from each sub-station is quite small. In most cases there is a definite schedule in accordance with which the trains are supposed to be worked, and it should be possible to calculate from this and from the curves shewing the power required by each train the maximum demand on each line, and the necessary section of conductor rail to keep the maximum drop within proper limits.

Take, for example, the following case: provision is to be made for a 2 minute service of trains in both directions along a double track line. Each track is equipped with two 100 lb. conductor rails, one for each polarity; the trains are equipped in such a way that the maximum current per train is about 2600 amperes at 500 volts; the average speed, including stops, is 15·6 miles per hour. Assuming that stations are on the average half a mile apart, and that sub-stations can only be situated at these stations, what is the best arrangement?

Consider the maximum drop if the sub-stations are spaced 1 mile, $1\frac{1}{2}$ miles and 2 miles apart, respectively. The average distance between trains on the same track is practically half a mile, and on this basis the trains will be distributed as in figure 257, taking into account a single track only, there being two symmetrical arrangements for each case. For each distribution the maximum drop can easily be calculated, the currents being as shewn, by taking the resistance of the conductor rail as

·032 ohms per mile single or ·064 ohms per mile go and return. (Thus 100 lbs. per yard is equivalent to 10 sq. inches, and with conductivity $\frac{1}{7 \cdot 5}$ times that of copper, resistance per mile $= \frac{\cdot 043}{10} \times 7 \cdot 5 = \cdot 032$.)

The various drops will therefore be:

$$\begin{array}{lll}
(a) & 1300 \times \cdot 064 \times \frac{1}{2} & = 41 \cdot 5 \text{ volts.} \\
(b) & 2600 \times \cdot 064 \times \frac{1}{4} & = 41 \cdot 5 \quad ,, \\
(c) & 1300 \times \cdot 064 \times \frac{1}{2} + 3900 \times \cdot 064 \times \frac{1}{4} & = 104 \quad ,, \\
(d) & 2600 \times \cdot 064 \times \frac{1}{2} & = 83 \quad ,, \\
(e) & 1300 \times \cdot 064 \times \frac{1}{2} + 3900 \times \cdot 064 \times \frac{1}{2} & = 166 \quad ,, \\
(f) & 2600 \times \cdot 064 \times \frac{1}{2} + 5200 \times \cdot 064 \times \frac{1}{4} & = 166 \quad ,,
\end{array}$$

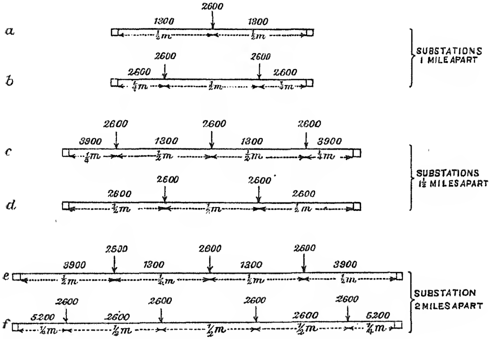


FIG. 257. Diagram of currents for various distributions of sub-stations.

It is quite evident from these results that the choice lies between distributing the sub-stations 1 mile and $1\frac{1}{2}$ miles apart.

The above forms only a simple illustration, and in actual practice it is in general necessary to look rather more carefully into the question of possible distributions of trains. It is, of course, only a rough assumption that trains keep at a constant distance apart; the necessity for stopping at intermediate stations and the exigencies of traffic are usually sufficient to render this out of the question. It may be taken as a more or less general principle that what may be called "normal" departures from the state of affairs laid down in the schedule must be provided for, but that only sufficient provision need be made for

"abnormal" circumstances to enable the service to be resumed as soon as possible, without caring for the efficiency, etc., under such circumstances. By "normal" departures are meant such as are constantly occurring due to slight delays or extra heavy traffic, and include such possibilities as stops for adverse signals and bunching together of trains. The limits of such departures are generally set by the block system working which prevents more than a certain amount of bunching. "Abnormal" circumstances are such as arise when breakdowns occur in one or other part of the installation; thus for instance suppose one sub-station breaks down entirely, it is unnecessary to make provision for running the service from the two neighbouring sub-stations with undiminished efficiency.

It is therefore advisable to pay careful regard to the distribution of the signals, as it is reasonable to assume that no train will take its maximum current except just after starting from a "stop" signal, whether "home," "starter" or otherwise; by paying attention to this fact it is often possible to arrive at the worst conditions as far as voltage drop is concerned, and a consideration of the schedule and the type of traffic will enable some estimate to be formed as to how frequently such conditions are likely to occur. Figure 260 shews an example of the plan of a line on which all the signals are marked.

As to what drop should be allowed will depend a good deal on how often the maximum is likely to occur. Thus, for instance, if the maximum does not occur more often than once or twice a day a comparatively large drop may be allowed. If, on the other hand, the worst circumstances recur several times in the course of a single journey the voltage should be kept within narrower limits. In tramway work a maximum drop of 80 to 100 volts is generally permitted with 550 volts at the generating station, but this is probably rather too much for the regular practice on electric railways. Thus, for instance, on the Central London Railway the greatest fall in voltage amounts to about 50 volts with 525 to 550 volts at the sub-station bus-bars; and on the Hammersmith and City Railway the low tension feeders have been laid out for a maximum drop of about 50 volts with 600 to 630 volts at the sub-station terminals. In other cases greater drops might be allowed provided the conditions did not occur too frequently.

The regulation of the transforming plant must also be kept in mind, as also the drop in the high tension feeders. The latter is generally small, whereas the former depends on the type of plant. This matter, however, is dealt with in chapter 20, pages 410, 411.

The question of cross bonding the conductor rails of two or more tracks. Sectionalising the low tension feeding system. The questions of cross bonding and sectionalising the distribution

system must be considered together in relation to the working of the railway and the requirements of the various departments concerned. An electric railway, such as is being discussed here, is a much more complicated institution than a tramway and has to be treated accordingly.

The practice of sectionalising the distribution system is derived from the necessity of localising as far as possible the disturbance caused by any unusual proceeding. In railway work there may be several reasons for working the traffic on a single line only, apart from any breakdown of the electrical arrangements, and means must be provided whereby repairs may be carried out on the permanent way without any danger of shock to the repairing gang. This may involve more elaborate arrangements than are usual on tramways, where the organisation of the traffic is not so strictly controlled.

The simplest procedure is to keep the conductors on the two tracks permanently separate, and to divide the line at suitable points, with arrangements whereby the supply to each section is controlled at the sub-stations. This is especially the case with "tube" railways where the "up" and the "down" line are in separate tunnels. Thus, for instance, on the Central London Railway, the conductor rail is divided opposite each sub-station, each section being fed from both ends through automatic cut-outs on the sub-station switchboards.

On the Hammersmith and City Railway, to be referred to at greater length below, the conductors are divided at the sub-stations and also between them, and the two tracks are bonded together through switches placed at suitable points. This method is not so simple as that mentioned above; but, by working two conductor rails in parallel, the voltage can be kept more nearly constant, or for the same maximum drop smaller conductors are required or more trains can be worked.

The precise methods of cross bonding and sectionalising are of considerable importance, and must be carefully examined. The object of cross bonding has already been stated, and the method of carrying it out must be such that when one track is under repair the connections must be opened. Switches must therefore be used which can be operated by authorised employés.

In the same way section divisions must be such that when they are open there shall be no possibility of a connection being made across them. On the Central London Railway, to take a typical case, the division consists simply of a short length of 3 or 4 feet between abutting conductor rails. On the Metropolitan District Railway, on which line a power cable extends the whole length of the train, joining together the collector shoes, an insulated or "train" section is introduced between adjoining sections, the length of which is such that no

train can bridge the gap between the two sections. This train section is separated by a short gap at each end from the abutting conductor rails and is fed by a special feeder from the sub-station bus-bars. Figure 258 shews their arrangement diagrammatically, A, B and C being three sub-stations; opposite to each is a train section S_a, S_b, S_c, and between each a section *ab*, *bc* of conductor rail. From the positive bus-bar of each sub-station are taken 3 feeders; thus, for instance, from B feeders go to *ab*, S_b and *bc*, each with its own switch. In the illustration the switches are shewn cutting out section *bc*, and for that purpose the two feeder switches supplying that section are opened, and also those supplying train sections S_b and S_c.

Metropolitan District Railway. The low tension feeder system on this Railway (part of which is shewn diagrammatically in figure 259) is an example of a line in which there are no cross connections between the conductor rails of the two tracks except at sub-stations and at signal boxes at junctions. The plan of the conductors does not require a detailed description, as all the arrangements are clearly shewn; but

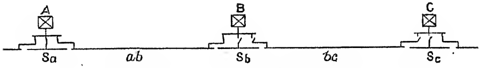


FIG. 258. Diagram shewing arrangement of "train" section.

attention may be directed to the train sections opposite each sub-station, and to the provision of similar sections at Mill Hill Park Junction.

Hammersmith and City Railway, low tension distribution system. The low tension distribution system on this line is of considerable interest, as it has been designed on the principle of taking full advantage of the conductor rails by cross bonding, while at the same time most careful precautions have been worked out to neutralise any danger to employés that might be caused thereby. It is interesting also from another point of view, in that the system that has been electrified contains one part on which the traffic is comparatively thick and another part where there are only two trains per hour each way.

The whole system is shewn, diagrammatically, in figure 260. As a preliminary it should be stated that on this railway the track rails do not form part of the electrical circuit; one of the conductor rails is placed outside the track, and the other in the centre, as shewn in the small diagram, figure 261. This small diagram illustrates in a general way the method of constructing a sectionalising division in the distribution system. As mentioned above in connection with the

Metropolitan District Railway, a train section is provided, but in this case the feeding of this section is quite different. At each end of the division there is a 6 inch gap in the conductor rails, filled in with a hard wood block. This gap can be, and in some cases is, bridged by a heavy copper strap fixed in position by phosphor bronze set screws. Between two such gaps there is a length of 315 feet of conductor rail, which forms the "train" section, the length between the front and rear collector shoes on a train being 310 feet. At one end of the train section are the gaps normally unbridged, and at the other end connections are made from the conductor rails to a switch pillar containing switches for bridging the gap. These switches are connected only to the positive rail, the negative rails being provided with straps. Close to signal boxes are situated the cross bonding connections, which consist of a pair of switches, one for the two positive rails, and one for the two negative rails. These switches are opened or closed as desired by means of rods and levers from the signal box.

These three types of apparatus, the strap, the section switches and the cross bonding switches, constitute the whole of the apparatus for sectionalising the distribution system and they are applied in different ways as required. Before going further, it is important to mention the regulations which have been prepared concerning the proper working of these various parts. It is, of course, essential that the control of the switches, etc., should be in the hands of the Traffic Department who are responsible for the working of the trains. Any alteration, therefore, of the normal arrangements can only be made with the authority of the station master or inspector. The employés working on the line itself belong to the Permanent Way Department, and are in charge of a ganger who is responsible for their safety and who makes the necessary arrangements with the Traffic Department.

In the section pillars the disconnecting switches are so constructed that the opening of any switch releases a tablet key, and the switch cannot be closed again until the key is reinserted in its lock. This tablet key serves as authority to the Permanent Way Department for removing the straps from the other three gaps of the train section on the one track, and is retained until the conductor rails may be made alive again. The switch pillar can only be opened or closed by the signalman or under the orders of the station master of the nearest station, and all such pillars are provided with telephone sockets, so that a portable telephone can be used for communication with the sub-stations or the nearest signal box.

Similarly, the opening of the cross bonding switches by a lever in a signal cabin releases a tablet key, without which the switches cannot again be closed.

Turning now to figure 260, it must be understood that all the gaps shewn with straps are normally bridged and all section and cross bonding switches closed with the following exceptions:

1. The switches in pillars 23 and 24 are kept open, thus separating the conductors on the Bishops Road to Hammersmith line from those of the Metropolitan Railway.

2. The gaps at the other end of the same "train" section are normally bridged only by electrical resistances designed to limit the rush of current between the two systems when the gaps at pillars 23 and 24 are bridged by trains.

3. Opposite each of the two sub-stations, viz. at Royal Oak and at Shepherd's Bush, short lengths of rail 40 feet long are provided with gaps at each end. These are for separating the sections fed by different feeders, and the straps bridging these gaps are normally removed.

4. The train sections at pillar 17 close to Westbourne Park are kept dead, the switches in this pillar being open and the straps at both ends removed. This separates the two sub-stations.

5. Special arrangements are made outside Addison Road Station.

6. The switch in pillar 1 is normally open.

A careful examination of the diagram will shew the arrangements at cross over roads and junctions. A gap is inserted in the centre of each cross over, so that the two tracks shall not be permanently cross bonded, and as a rule cross bonding connections are provided close to these points. It will also be seen that the divisions in the distribution system are so placed that, when the necessity arises for single line working, a train can always run beyond the points of the cross over without running on to the dead section, so that it can back on to the other line without difficulty.

Thus, for example, supposing the lower track between S.I.D. and S.I.E. has been made dead, a train running from Westbourne Park to Latimer Road would be able to cross over to the upper track by the cross over road just west of Westbourne Park, and would proceed past the dead section until it reached the cross over road at Latimer Road.

The traffic on the line between Latimer Road and Addison Road consists only of two trains per hour each way. It is, therefore, not worth while to put down a sub-station for the special purpose of feeding this branch; and cables are run from the Shepherd's Bush sub-station to feed this portion of the railway. The arrangement of the feeder and of the two sectional divisions S.I.E. and S.I.H. are clearly shewn in the diagram.

Low tension feeders are also laid along the line to the Hammersmith end, for the double purpose of keeping down the voltage drop at the far end and of providing an independent supply for the train sheds. The arrangement of switches is such that either cable or both together can be switched on to the train sheds or on to the conductor rails.

[It may be mentioned here that in the train sheds current is supplied to the trains from an overhead trolley by means of a flexible cable and a plug. The supply in these sheds is normally kept separate from that to the conductor rails outside by the train section at pillar 1 being normally dead.]

It will thus be seen that the whole of the distribution system has been planned so as to provide for every contingency*.

The use of the track rails for the return current. It will be evident to anyone studying the more recent work in direct current electric railways that it is usual to adopt the system of distribution with two insulated rails, leaving the track rails untouched. This is, no doubt, partly owing to the fact that the first electric railways were comparatively small, that is to say, the currents to be dealt with were such that no difficulty was experienced in keeping within the Board of Trade limit of 7 volts drop in the return, without any special arrangements beyond bonding the track rails. As the power to be transmitted increased owing to the use of heavy trains and high accelerations, it became obvious that a limit of 7 volts drop in the return was a severe handicap on the distribution system, and that it was cheaper to use two conductor rails and so avoid the limit. There should be no difficulty in any particular case in determining whether there is any advantage to be gained by using the track rails; but a simple example may make the matter clear.

Compare the conductivities of a 100 lb. conductor rail and two 85 lb. track rails. The resistance per mile of the conductor rail (assuming conductivity $\frac{1}{7{\cdot}5}$ times that of copper) $= \frac{{\cdot}043}{10} \times 7{\cdot}5 = {\cdot}032$ ohm; the resistance of the two track rails (assuming conductivity $\frac{1}{12}$ times that of copper) $= \frac{{\cdot}043}{2 \times 8{\cdot}5} \times 12 = {\cdot}03$ ohm. A reference to the example worked out on page 393 will shew that the sub-stations would have to be very close together indeed to keep the rail drop to within 7 volts.

* The authors are indebted for the above information to Mr Roger T. Smith, the Electrical Engineer of the Great Western Railway, and to Messrs Kennedy and Jenkin, the consulting engineers for the electrification; to these gentlemen they wish to tender their thanks.

Apart from this question, however, there is the consideration that if both poles are insulated an accidental earth on one pole need not cause any interruption of the service, whereas if one pole is permanently earthed any connection of the live rail to earth puts a stop to the supply until the connection has been removed.

The auxiliary feeder system in connection with electric tramways was taken to include the telephone and test cables. In electric railways there are frequently other cables such as those for lighting tunnels and stations, and in the case of "tube" railways those required for working the lifts. These cables are not peculiar to any system of traction and need not be discussed at length here. It will be sufficient to mention the advisability of keeping the supply for these subsidiary purposes distinct from that for the working of the trains, so that any accidental short circuit on the traction system shall not simultaneously extinguish the lights.

The diagram of these auxiliary feeders for the Central London Railway is shewn in full detail in Plate lxv. of the paper by Messrs Parshall, Hobart and Casson (*Traction and Transmission*, vol. 7, page 268).

The high tension feeder system. It is usual to supply power to the sub-stations by means of three-core three-phase cables from the generating station.

With regard to the general design of the high tension feeder system, it is important to note that there are no Board of Trade Regulations to be complied with, such regulations as have been issued in connection with extra high pressure supply dealing only with electric lighting installations. The design of the high tension cables, therefore, for electric railways must be regarded purely as an engineering problem. The chief considerations are, of course, continuity of supply and general economy.

To ensure continuity it is the general practice to provide at least a duplicate system, so that one feeder may be used alone to maintain the supply while the other is under repair. With this as a general principle, there are several ways of designing the system. The most obvious way is to lay two separate cables to each sub-station, so that if there are n sub-stations supplied from a single generating station, there will be $2n$ high tension feeders. This method has advantages and disadvantages; it is generally rather more expensive than other systems; but on the other hand it enables the generating station staff to keep complete control over the supply to each sub-station.

A more economical method, applicable to a case in which the sub-stations are situated at intervals along the route of the cables to the

furthermost feeding point, is to provide only two cables with junction boxes at each tapping point. Figure 262 shews this method diagrammatically, X being the generating station, A, B, C, D the sub-stations, and F_1, F_2 the two feeder cables. At each sub-station two junction boxes receive the ends and connect them to the bus-bars as shewn. Figure 263 shews the method of connecting the cables in the junction boxes as designed for the Central London Railway. In this figure four three-phase feeders are shewn connected in two pairs; the feeders F_1, F_2 are taken to box J_2, and the feeders F_3, F_4 to box J_1. In each of these boxes shewn diagrammatically in the figure are twelve links, whereby the

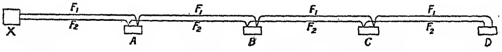


FIG. 262. Diagram of high tension feeder system.

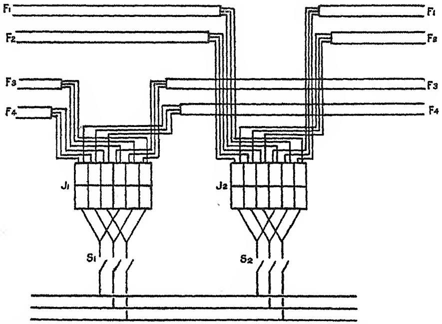


FIG. 263. Diagram of high tension junction boxes on the Central London Railway.

incoming feeders are connected to the corresponding outgoing feeders, and to the bus-bars of the sub-station. It will be seen that F_1 and F_2 are connected in parallel on to the three poles of the switch S_2, and F_3 and F_4 are likewise in parallel on the switch S_1, and if both switches be closed, all four feeders are put in parallel by the bus-bars. With this arrangement any faulty length of cable can be cut out for repair by first opening all the switches S_1 or all the switches S_2 and then disconnecting the cable by taking out the links at both ends of the faulty section.

A third method consists in the combination of the two already mentioned. A single feeder is taken to each sub-station and all the

sub-stations are joined together by inter-connecting feeders. Thus if any one of the direct cables breaks down, the necessary supply can be maintained from two neighbouring sub-stations through the inter-connectors. This system has the advantage of providing a duplicate supply by different routes, so that the burning out of one cable cannot disable another, as might happen with two cables laid alongside each other. Figure 264 shews a diagrammatic illustration of this method.

If the load on each sub-station is kept approximately constant, it is evident that in the last system the interconnectors are normally idle; and as the direct feeders must be designed both for economical working and also with a view to supply power for more than one sub-station over a single cable, the system is not theoretically so economical as the first mentioned in which each sub-station is fed direct with duplicate feeders. The extra cost is not so great, however, as might appear at

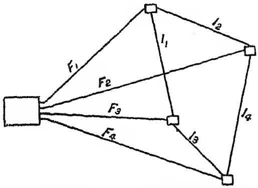


FIG. 264. Diagram of high tension feeding with inter-connecting cables.

first sight, since the prices for high tension three-phase cables are by no means proportional to the cross-section of the copper conductors. This is especially so with small cables; thus, for example, the approximate costs for 11000 volt three-phase cables with conductors ·025 and ·05 square inches in section are* £348 and £480 per mile respectively, that is to say corresponding to an increase of 100 per cent. in the cross-section of the copper, the increase of price is only 38 per cent.

When it is a question of distributing on a very large scale to a number of sub-stations, it is probably advisable to adopt the system of separate duplicate feeders to each sub-station. This keeps the cables down to sizes that are easily manageable and moreover enables the generating station staff to keep absolute control over the supply.

* Plain lead covered cable with centre earthed, prices based on copper wire at 9*d.* per lb. and lead at £15 per ton.

The calculations for the proper section of cable have already been considered in chapter 9, and it is only necessary to remark here that in the duplicate system, the cables must be designed so that when only one of a pair is in use the current density shall not at any time (except for momentary fluctuations) exceed 1000 amperes per sq. inch. This requires, therefore, that in normal working the current density will not exceed 500 amperes per sq. inch.

The following example may be given:

London Underground Electric Railways*. Duplicate or quadruplicate cables to each sub-station except one (11000 volts, $33\frac{1}{3}$ periods).

Sub-station	Sub-station plant	Cables three-phase three-core sq. in.	Length from generating station miles
East Ham	3 × 1200 kw.	2 each ·243	13·34
Campbell Road Junction	3 × 1200 ,,		10·35
Whitechapel	4 × 1500 ,,	4 ,, ·184	8·15
Mansion House	3 × 1500 ,,	2 ,, ·243	6·37
Charing Cross	4 × 1500 ,,	4 ,, ·184	5·07
Victoria	3 × 1200 ,,	2 ,, ·243	3·72
South Kensington	3 × 1500 ,,	2 ,, ·243	2·31
Earl's Court	4 × 1500 ,,	4 ,, ·184	1·30
Putney Bridge	3 × 800 ,,	2 ,, ·149	3·29
Wimbledon Park	3 × 1200 ,,	2 ,, ·243	5·83
Ravenscourt Park	3 × 1500 ,,	2 ,, ·243	3·27
Kew Gardens	3 × 1200 ,,	2 ,, ·243	6·10
Mill Hill Park	4 × 1200 ,,	4 ,, ·149	5·45
Hounslow Town	3 × 800 ,,	2 ,, ·149	9·90
Sudbury Town	3 × 800 ,,	2 ,, ·149	9·59
Euston Station	3 × 800 ,,	2 ,, ·149	6·62
Kentish Town	3 × 800 ,,	2 ,, ·149	8·30
Belsize Park	3 × 1200 ,,	2 ,, ·243	9·15
Golders Green	4 × 800 ,,	4 ,, ·149	11·36
Hyde Park Corner	3 × 800 ,,	2 ,, ·149	3·34
Russell Square	3 × 1200 ,,	2 ,, ·243	5·62
Holloway	3 × 1200 ,,	2 ,, ·243	7·83
Baker Street	3 × 800 ,,	2 ,, ·149	7·37
London Road	3 × 800 ,,	2 ,, ·149	6·42

Cable laying. Some practical information has already been given (see chapter 9) with regard to cable laying, and it is only

* *Street Railway Journal*, March 4, 1905, p. 407.

necessary here to touch upon those points in which the cable system for electric railways differs from other systems.

In "tube" or "tunnel" railways it is possible to effect a considerable economy in the cost of installing the cables by fixing them on brackets fastened to the tube or tunnel wall. They may there be covered in by sheet iron covers which are easily removeable for purposes of inspection or repair. Figure 265 shews the type of bracket used on the Central London Railway.

In some cases cast iron troughs are supported from the tunnel wall and cables laid solid in them in the usual manner. Where a line

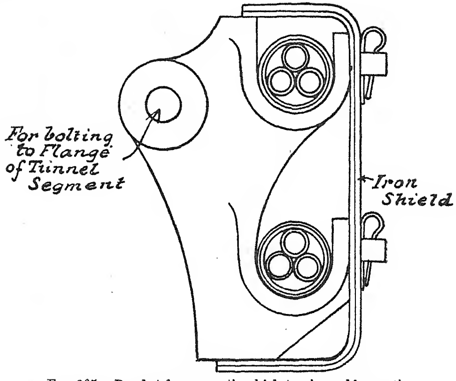
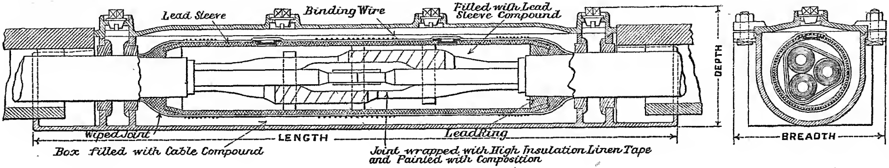


FIG. 265. Bracket for supporting high tension cables on the Central London Railway.

of cables passes under a railway track it is advisable to build a small culvert over the troughing, so that the vibrations caused by passing trains may not be transmitted to the troughs and cables; otherwise there is danger of the trough and the compound within being broken across.

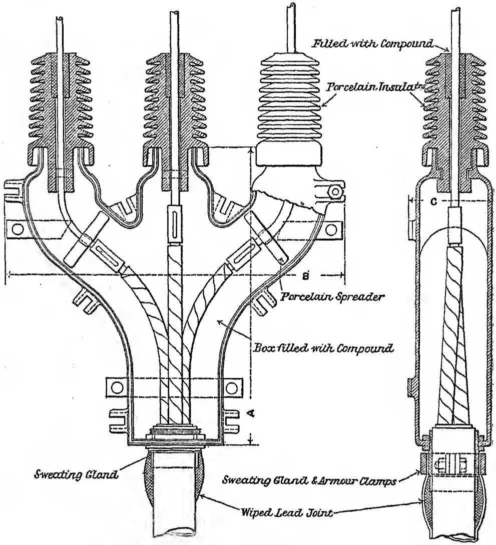
Joints in high tension three-phase cables are made with lead sleeves as already described (page 206); figure 266 shews such a joint in section as made by Messrs Callender Co. Where, however, such cables terminate, as, for instance, when they reach the terminals of switches in sub-stations or generating station, they are led into a trifurcating box in which the three cores are separated and the ends sealed with



Voltage	Section of core in sq. in. up to	Outside size of box		
		Length	Breadth	Depth
12000	·05	34¾″	9″	7¼″
,,	·10	39½″	9½″	7¾″
,,	·15	,,	,,	,,
6000	·10	34¾″	9″	7¼″
,,	·15	39½″	9½″	7¾″
,,	·25	,,	,,	,,

FIG. 266. Three-phase extra high tension straight jointer box. (Callender Co.)

compound; the cores leave the box through three separate holes bushed with porcelain. Such a trifurcating box as manufactured by Messrs Callender Co. is illustrated in figure 267.



Section of core	Length A	Breadth B	Depth C
·05 sq. in.	$20\frac{3}{8}''$	$23\frac{3}{4}''$	$5\frac{3}{4}''$
·15 ,,	,,	,,	,,

FIG. 267. Trifurcating box for three-phase high tension cables. (Callender Co.)

The following information* may be found useful in dealing with the extra high tension three-phase cables:

* These tables have been kindly given to the authors by Messrs Siemens Brothers and Co., and apply to cables made by this firm. Particulars of cables by other firms will only differ very slightly in one or two respects.

Three-phase three-core 6000 volt paper insulated lead covered cables with copper sheath.

Area sq. in.	Diam. over lead ins.	Length per drum yds.	Gross weight per drum cwts.	Shipping dimensions	Weight of compound per 1000 yds. cwts.
·025	1·394	640	56	69″ × 69″ × 41″	51
·05	1·534	500	"	"	55
·075	1·679	405	"	"	60
·1	1·794	360	"	"	64
·15	1·964	290	"	76″ × 76″ × 37″	70
·2	2·104	240	56½	74″ × 74″ × 42″	75
·25	2·284	205	"	"	81

Three-phase three-core 10000 volt paper insulated lead covered cables with copper sheath.

Area sq. in.	Diam. over lead ins.	Length per drum yds.	Gross weight per drum cwts.	Shipping dimensions	Weight of compound per 1000 yds. cwts.
·025	1·814	420	57	77″ × 77″ × 41″	64
·05	1·954	340	"	"	69
·075	2·074	305	"	"	74
·1	2·214	260	"	75″ × 75″ × 47″	79
·15	2·384	220	"	"	85
·2	2·524	190	"	77″ × 77″ × 41″	90
·25	2·704	160	"	"	96

NOTE. The above particulars are for cables on systems where the centre point of the star is not earthed.

CHAPTER 20.

SUB-STATIONS FOR DIRECT CURRENT RAILWAYS.

The equipment of railway sub-stations. General. The purpose for which sub-stations are provided is to perform the necessary transformation of the energy received from the generating station to the energy in the form required by the electrically propelled trains. As far as direct current railways are concerned it is almost invariably the case that electric energy is transmitted to the sub-stations as three-phase high tension alternating current, and transformed to low tension direct current at about 500 to 600 volts. The equipment of a sub-station will, therefore, correspond to this requirement, and will consist of apparatus for effecting the desired transformation.

There is at present no type of machinery available for this transformation other than motor generators and rotary converters, and motor converters which are practically intermediate between motor generators and rotaries. The former require very little explanation as they consist of direct current generators driven by alternating current motors. Rotary converters are not so simple, but are by this time well known; they are single machines very similar to direct current generators with the addition of slip rings and connections therefrom to fixed points of the armature windings. Alternating current, generally three-phase, is applied to the slip rings at a suitable voltage, and direct current is taken from the ordinary brushes which bear on the commutator. The motor converter is dealt with below.

In addition to the transforming plant there must be the accompanying switchboard, and there may be a storage battery with boosters automatic or non-automatic. The usual small accessories must, of course, be provided, such as lifting tackle, and occasionally offices for the attendants.

The subject of sub-station equipment is a special study, and is not peculiar to electric traction: the question will be treated here only in those aspects of it which concern the electric traction engineer in particular.

Motor generators and rotary converters. Before dealing with the capacity of the transforming plant in the sub-station, it is necessary to consider the choice between motor generators and rotary converters.

One of the most important considerations that affect the electric railway sub-station is economy of space; in many cases it is essential that the plant should be contained within the smallest possible dimensions. In this respect the rotary converter has a distinct advantage as an example will show.

In the Putney sub-station* of the Metropolitan District Railway Company there are installed three 800 kw. rotary converters, and their accompanying step-down transformers. The floor space occupied by each rotary together with its starting motor is approximately 11 ft. 4 inches by 10 feet, and by the three 300 kw. transformers connected thereto 14 ft. by 4 ft. Thus the total floor space is

$$11{\cdot}3 \times 10 + 14 \times 4 = 170 \text{ sq. feet.}$$

This may be compared with the large motor generators in the sub-stations of the Charing Cross and City Company†. In this case the set consists of a 700 kw. direct current motor coupled to a three-phase 10000 volt induction motor and the floor space occupied is about 16 ft. 9 ins. by 13 ft., giving an area of 218 sq. ft.

If, for the sake of comparison, the floor space in each case be expressed in terms of square feet per kw., the figures are as follows:

Rotary converter	·21 sq. ft. per kw.
Motor generator	·31 " "

In other words, a motor generator set requires about 50 per cent. more floor space than a rotary converter with its transformers.

A further advantage possessed by the rotary converter is its flexibility in arrangement. A motor generator is an indivisible unit as far as the space occupied is concerned, whereas there is no necessity to put the transformers in any definite relation to their rotary; they may be put on the floor above or below, or arranged round it if required, as in circular sub-stations.

Another important advantage pertaining to the rotary is that it is a low voltage machine. In the motor generators mentioned above the high voltage of the transmission system is brought on to the stator windings, whereas with the rotary converter system, this voltage is applied to stationary transformers. It is well known that when high alternating voltage is applied to a winding there is a danger that the

* See *Street Railway Journal*, March 4, 1905.

† See Mr Patchell's paper before the Institute of Electrical Engineers, Dec. 7, 1905.

part of the winding nearest to the point of application may break down, owing to capacity effects causing the full voltage to be concentrated momentarily on the first few coils. This may be met by insulating these coils to withstand the full voltage, and this can be done with greater ease in a stationary transformer than in the stator of an induction motor.

Rotary converters are not so easily regulated as to voltage as direct current generators, but this is of very little consequence to the electric railway engineer, as his requirements in this respect are not very severe and can be met by the converters on the market.

It has been objected that rotaries are liable to hunt, but this trouble has been successfully overcome, chiefly by attending to the uniformity in the angular velocity of the generating sets in the power house.

The question of efficiency is, naturally, important, and may be illustrated from the example given above.

For the 800 kw. rotary converter the combined efficiencies of converter and transformers are as follows:

One and a quarter load	93·4 per cent.
Full load	93 „
Three-quarter load	92 „
Half load	89·5 „

The efficiencies of the 700 kw. motor generator set have not been published, but they may be estimated as follows*:

	Generator	Motor	Combined
One and a quarter load	95 per cent.	94·5 per cent.	90 per cent.
Full load	95 „	95 „	90·5 „
Three-quarter load	94·5 „	95 „	90 „
Half load	93·5 „	94 „	88 „

On the average the difference in favour of the rotary converter is from 2 to 2½ per cent.

The above reasons may be considered sufficient for the general preference of rotary converters to motor generators for direct current railway sub-stations.

La Cour motor converter. Quite recently Messrs Bruce Peebles have introduced the La Cour motor converter, which consists of an induction motor coupled direct to a rotary converter. The high tension three-phase supply is connected to the stator winding of the induction motor, and the rotor windings are wound in several phases and these phases are connected to a number of points of the armature

* Compare the curves for the 500 kw. motor generator made by the Oerlikon Company, *Electrical World and Engineer*, Oct. 3, 1903, p. 574.

windings of the rotary converter. The latter supplies direct current in the usual way. This motor converter may be considered as intermediate between the motor generator and the rotary, inasmuch as the direct current machine generates part of its output due to its being driven mechanically by the induction motor, and produces part of its output by transformation from the rotor windings of the motor*.

The advantages claimed for this type of converter are that it combines many of the good points of the rotary with those of the motor generator. It is especially applicable to frequencies of 40 and 50 per second, which are not so favourable for rotary converters as frequencies of 25 and 30 per second. It is self starting from the three-phase side, by means of a starting switch of the usual type applied to the rotor windings. It does not require any step-down transformers, the induction motor being itself a transformer both electrical and mechanical. It is capable of direct current voltage regulation—10 per cent. up or down—or of compounding without the power factor of the supply being affected; and it has a high efficiency, the figures for the 500 kw. set for Manchester Corporation being 91 per cent. on full load and 85 per cent. on quarter load†.

It is interesting to note that motor converters of this type have been installed in the sub-stations of the Hammersmith and City Railway. In this case the alternating current supply is at 50 periods per second, the choice of this frequency being dictated chiefly by the requirements of the electric lighting demand, which will ultimately amount to 30 per cent. of the total.

Capacity of sub-station plant. The same two considerations apply to the sub-station plant as to almost all kinds of traction apparatus, viz. the influence of the maximum and of the effective mean. That is to say, the transformers whether stationary or rotating must be capable of dealing with the maximum demand and must be designed so that the root mean square current does not produce overheating.

As far as motor generators are concerned, the remarks already made in chapter 10 with regard to the capacity of the generating plant for direct current tramways are equally applicable to direct current railways, both for the generators and for the motors. That is to say, it is advisable to limit the overload of a generator under normal

* For a more complete description of this apparatus, see *Electrician* for March 30, 1906, p. 956.

† It is only fair to remark that the makers of rotary converters claim that their machines can be made perfectly satisfactory for a frequency of 50 periods per second, and that overcompounding to almost any extent can be provided. See Mr Miles Walker's paper before the Manchester section of the Institute of Electrical Engineers, Dec. 4, 1906.

circumstances to 50 per cent., and to make the motor large enough to drive the set under these circumstances. The motor, however, if of the induction type, needs a few special remarks. Occasionally very severe overloads will occur due to momentary short circuits and it is, of course, essential that the motor generator should not pull up and be unable to recover itself. The general specification for such a motor is that it will stand temporary overloads of at least 150 per cent., and it is probable that this condition will satisfy all the demands likely to be made on it.

It is well known that the action of a rotary converter as a kind of a sieve is such that the armature can be loaded far more than could be done with a direct current generator for the same heating. It might be thought, therefore, that the permissible overload might be extended for the same reason. It is necessary, however, to keep in mind that the sparking is very little affected by the fact that the machine is operating as a converter, and it is advisable to keep to the same limits as are usual with direct current generators, that is to say, overloads of not more than 50 per cent.* Thus the specification for the rotary converters in the sub-stations of the London Underground Electric Railways †, the capacities of which are 800, 1200 and 1500 kw. variously, is that no adjustment of the brushes is necessary between the limits of no load and 50 per cent. overload, and no injurious sparking or permanent injury will result from occasional momentary fluctuations reaching two and one-half times the normal full load. The machines are also guaranteed not to fall out of step with three times full load. The La Cour motor converters being partly rotary converters and partly motor generators should be subject to the same limitations as regards maximum output.

The capacity of the sub-station must be considered, not only from the point of view of what overloads are permissible on any individual machine, but also in the light of the total number of units to be installed to meet the maximum demand on the sub-station, and to provide a reasonable spare capacity. This question is one which cannot be decided for the general case; circumstances must be taken into account, more particularly, how far any sub-station is always self-dependent or can be assisted by neighbours.

As an example, on the Central London Railway each sub-station contains two rotary converters and seven transformers. Each rotary is

* Mr Miles Walker in his paper before the Manchester section of the Institute of Electrical Engineers, Dec. 4, 1906, quotes the case of a 40 cycle rotary which ran quite sparklessly at 90 per cent. overload. The whole question of overloads is however apt to be artificial, unless machines are designed so as just to fit the specification at the normal full load.

† See *Street Railway Journal*, March 4, 1905, p. 408.

capable of taking the load and forms a complete unit with three transformers. Thus there is 50 per cent. spare capacity together with a spare transformer to replace any one of the six normally connected up.

Another consideration which should be remembered applies more particularly to systems containing several sub-stations, namely, the advisability of keeping to a few standard sizes. Thus, for instances, the transforming plant laid down by the London Underground Electric Railways consists of 77 rotary converters, for all of which there are only three alternative sizes, namely, 800 kw., 1200 kw. and 1500 kw.

Storage batteries in sub-stations. There seems to be no generally accepted practice with regard to storage batteries in traction sub-stations. In many cases there are no batteries at all; in other cases there are small batteries which are used only for lighting purposes; and in a few cases only there is sufficient storage capacity to take the peak loads on the traction circuits.

Examples of these various cases may be given as follows: As instances of sub-stations in which there are no batteries at all, those installed by the London Underground Electric Railways may be quoted, also those on the Liverpool-Southport line, and those on the Tyneside branch of the North Eastern Railway. As an instance of a sub-station which has associated with it a small battery for lighting purposes mention may be made of the Post-office sub-station on the Central London Railway. As examples of storage batteries working in parallel with motor generators or rotary converters in traction sub-stations there are instances on the Hammersmith and City Railway, and on the New York Central and Hudson River Railroad*.

In the case of the Hammersmith and City line, the transforming plant at the Shepherd's Bush sub-station consists of six 400 kw. motor converters working on the traction load and two 200 kw. motor converters for lighting. In conjunction with these sets there is installed a storage battery with a capacity of 1680 amperes for one hour, connected to the traction bus-bars (600—630 volts) through an automatic reversible booster. In the Royal Oak sub-station the plant consists of four 400 kw. and two 200 kw. motor converters, together with a battery giving 840 amperes for one hour. These batteries are specially designed for a double purpose; first, they deal with the peak loads on the traction system in ordinary working, and secondly they provide a stand-by in case of any failure of the generating station. In this scheme the lighting load, which amounts to as much as 30 per cent. of the total, is of greater importance than the

* See *Street Railway Journal*, November 3, 1906, p. 876.

traction load as it supplies current for the illumination of all the approaches to Paddington, the main line terminus of the Great Western Railway. If any accident occurs in the generating station, the high tension supply is cut off, and simultaneously the traction supply is automatically discontinued. Under these circumstances, the battery is left connected to the D.C. end of the motor converters which are kept running thereby, and the function of the converters is inverted, their duty being to take direct current from the battery and to transform it to high tension alternating current which is supplied to the lighting distributors. Thus the battery acts as a stand-by for the generating station as well as an equaliser.

On the New York Central and Hudson River Railroad there are eight sub-stations each containing three rotary converters; in two cases these converters are of 1500 kw. capacity each, and in the others 1000 kw. The largest battery has a capacity of 4020 amperes for one hour (bus-bar voltage 666), two others have capacities of 3750 and 3000 amperes for one hour, and the remaining five 2250 amperes for one hour. These batteries are provided chiefly for the equalisation of the load on the rotaries; but they are of sufficient capacity to operate the entire system for one hour.

Battery sub-stations. So far only transformer sub-stations have been considered, the purpose of which is solely to supply electrical energy at a suitable voltage. There is, however, another type which is worthy of mention, namely, the battery sub-station which contains no transforming plant, but only a storage battery. The function of buffer batteries has already been fully dealt with, and so far it has been assumed that they have been installed in the generating station, or else in sub-stations in parallel with generating or transforming machinery. In certain cases, however, there is an advantage in subdividing the buffer battery in the generating station and distributing it in the sub-stations along the railway. The total battery capacity may remain unaltered, but if it is distributed it will be utilised for two purposes instead of one only. When concentrated in the generating station it equalises the load on the generators, but if distributed it equalises not only the generator load, but also the load on the transmitting feeders. This may prove a considerable advantage in first cost, and in all round economy.

A good example may be quoted from the high tension direct current railway recently equipped by Messrs Siemens Schuckert. On this line, which is 28·3 kilometres in length, there is one express train every hour between Cologne and Bonn, stopping once on the way, and every half-hour a slow train stopping at all intermediate stations. It is evident, therefore, that the traffic is by no means dense; and as

the generating station is situated close to the centre of the line, all necessity for alternate current transmission and transforming plant can be avoided by providing battery sub-stations.

The general arrangement is shewn in figure 268. The overhead line for each track consists of two 80 sq. mm. copper wires, divided in sections as shewn. Two feeders go to the two central sections from the generating station and two feeders run parallel to the line, one to each sub-station. Each of the long distance feeders is supplied from the positive bus-bars through a booster which compensates for the drop in transmission. In the generating station and in each sub-station there is a battery with a 330 ampere hour capacity (on a one hour rating) working in conjunction with an automatic reversible booster. The section of each feeder is 125 sq. mm. Consider now the conditions of working due to a single train on one of the outer sections. The maximum current required by a full-sized train (consisting of two motor cars and two trailers) is 600 amperes at 1000 volts. This

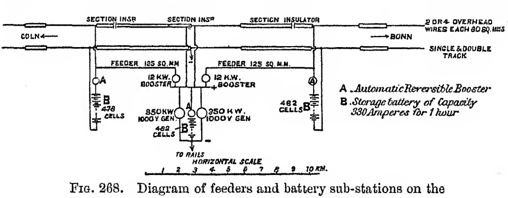


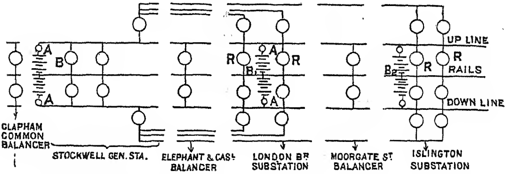
FIG. 268. Diagram of feeders and battery sub-stations on the Cologne-Bonn 1000 volt direct current railway.

current may be divided between the battery and feeder, the former taking say 400 amperes and the latter 200. The drop in the latter (taking the feeder towards Cologne) with 200 amperes is 155 volts, and this voltage must be supplied by the booster, which is designed to take this load of 31 kw. for short periods. Now if all the batteries had been concentrated in the generating station, in the first place negative feeders and negative boosters would have been necessary, and in the second place very different arrangements would have been necessary for the long distance feeders and their boosters. If 600 amperes were transmitted along the feeder already mentioned the drop to be compensated for would be 465 volts, and the momentary output of the booster would be 600 × 465 watts or 280 kw. If the feeder were doubled the momentary output would be 140 kw. and the extra copper for the one feeder alone would cost about £800 to £900. The economy of the present arrangement is, therefore, considerable.

City and South London Railway. The electrical arrangements of the sub-stations and the transmission system on this railway are peculiar, and may be said to be a combination of the two types already described in that the sub-stations contain motor generators as well as buffer batteries.

The outlines of the system are shewn diagrammatically in figure 269. The up and the down lines are in separate tunnels and the distribution to the conductor rails is on the three wire system, the track rails forming the central conductor. The one conductor rail is 500 volts above the earthed return and the other 500 volts below.

In the generating station at Stockwell the main generators work in parallel with a 1000 volt battery with an automatic booster, and supply current to the up and down conductor rails. The sub-stations at London Bridge and Islington are connected with the generating station by feeders to which current is supplied from the plus and minus bus-bars through boosters which raise their pressures to 1000 volts above and



A Automatic reversible booster.
B 500 cells 75 amperes for 3 hours.
B_1 556 cells {150 amperes for 3 hours. / 300 amperes for 1 hour.}
B_2 500 cells 180 amperes for 3 hours.
R Reducer set consisting of 4 machines in series: the capacity of a pair being 300 kw. continuously at 1000 volts or 400 kw. for 2 hours.

Fig. 269. Diagram of feeders and sub-stations on the City and South London Railway.

1000 volts below the neutral. Thus the transmission to the sub-stations is effected at 2000 volts direct current. At the sub-stations this supply is reduced to plus and minus 500 volts at which voltage the conductor rails are fed. The reducers, of which there are two in each case, consist of four machines with their armatures connected in series across 2000 volts; each armature is designed for approximately 500 volts, and the capacity of a pair of machines is 300 kw. continuous load at 1000 volts or 400 kw. for 2 hours. In parallel with the two reducers in each sub-station is a battery; at London Bridge the battery contains 556 cells with a capacity of 150 amperes for 3 hours, and at

Islington 500 cells with a capacity of 180 amperes for 3 hours. Each half battery is connected to the conductor rails through an automatic reversible booster on the Highfield system. Special arrangements are made in the reducers for compensating for the drop of voltage in the 2000 volt feeders, so that the volts on the conductor rails at the feeding points are kept constant at 500 plus and minus, whatever the current in the feeders may be.

It is important to observe that in this system only half the power supplied by one of the high tension feeders is actually transformed by the reducers, and since the peaks are taken up by the storage battery it is obvious that the sub-station efficiency must be very high. A large number of tests have been given by Mr McMahon in his paper before the Institution of Electrical Engineers on Dec. 17, 1903, from which the following abstract may be quoted:—"the efficiency of distribution being as follows:

Stockwell	99·3	per cent.
Kennington	96·6	,,
London Bridge	86·0	,,
(Islington) Angel	81·6	,,

the average efficiency over the whole system being 90·9 or say 91 per cent....the average loss between the ends of the feeders and the locomotives is well covered by 1 per cent. The net efficiency of transmission from the switchboard in the generating station to the locomotives is thus 90 per cent.*"

Portable sub-stations. On some lines in the United States portable sub-stations are provided, which can be utilised at any point of the system in case of the breakdown of any regular plant. As an example the case of the Wilkesbarre and Hazleton Railway† may be quoted.

The sub-station consists of a double bogie car built to the usual gauge and about 36 feet long. It contains a 400 kw. rotatory converter with its starting motor, the necessary switchboard and connecting cables, and three 150 kw. step down transformers. The bogies are of the trailer type without any motor equipments, so that the sub-station is not self-propelling. The disposition of the apparatus is such that the weight is concentrated as much as possible over the bogies, the rotary being at one end and the three transformers at the other end, the switch-board being in the centre. The underframe of the car body is strengthened transversely and longitudinally, the total weight of the equipment being about 23 tons.

* For more complete information regarding this railway see *Electrician*, vol. 48, pp. 167, 256, 337, 529, 564, 684, 774 and 850, also Mr McMahon's paper reported in the *Electrician*, vol. 52, pp. 323 and 363.

† *Electrician*, October 14, 1904, p. 1029.

The maximum demand on a sub-station. In the foregoing pages the equipment of a sub-station has been discussed in relation to the maximum demand; it is necessary to make a few remarks on the magnitude of this demand. In some cases there is no difficulty in predicting what the output will be, as for example when the sub-station has to supply only one unit or train at a time. In such a case the demand on the generating plant is determined entirely by the capacity of the train equipment.

In another extreme case, viz. when a single sub-station or generating station supplies a large number of units, the output does not differ greatly from the mean which will be the sum of the average demands of all the units. Such a case is of frequent occurrence in tramway systems of a fair magnitude, but is the exception for railway sub-stations.

The more frequent case in railways is where each sub-station feeds a few trains only, the number however being such that it is not reasonable to add together the maximum of each of the units. In such a case it is impossible to say with certainty what the maximum demand will be, and it must be left to the individual judgment of the engineer to decide what plant should be put in. There can be little doubt, however, that it is best to err on the side of safety by putting in ample capacity; for it is of vital importance to the railway that there should be as few as possible interruptions in the regular working of the traffic.

Two examples of sub-station output curves are shewn in figures 270 and 271*. The former of these was taken at the Mansion House sub-station and the latter at the Victoria sub-station of the Metropolitan District Railway at about 6 o'clock in the evening, the traffic being greatest at this time. The curves in these figures shew that the current varies very greatly in the latter case, reaching zero three times in nine minutes. In both figures there are indicated the times at which trains of the various types started from the stations, and in this connection it may be stated that the approximate values for the maximum current in each case are as follows:

Metropolitan District train	(D.)	about 1600	amperes
Metropolitan train	(M.)	„ 1800	„
London and North Western train	(L.N.W.)	„ 2000	„
London and North Western loco	(L.N.W.L.)		

The average speed of all the trains is about 13 miles per hour†.

* The authors are indebted to Mr Casson for permission to obtain these curves in the sub-stations under his control.

† Since these tests were taken the average speed has been raised to about 16 m.p.h.

Fig. 270. Fig. 271.

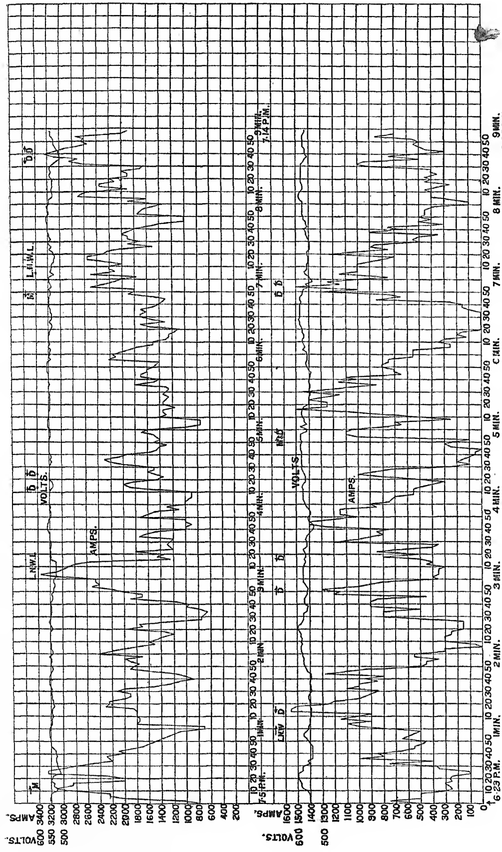


Fig. 270. Curves of voltage and current output at the Mansion House sub-station of the Metropolitan District Railway.

Fig. 271. Curves of voltage and current output at the Victoria sub-station of the Metropolitan District Railway.

It is interesting to note that the variation of output at the Victoria sub-station is greater than at the Mansion House. This is chiefly due to the fact that the former is not very far from a large sub-station at Charing Cross, which would take a considerable portion of the load between it and Victoria.

In the Mansion House sub-station the transforming plant consists of two 1500 kw. rotary converters, only one of which was working at the time of the test. At Victoria there are two 1200 kw. converters, of which one was working. In both figures the voltage curves are shewn, and are of interest in connection with the fact that the converter at the Mansion House was using its compound field winding, whereas that at Victoria it was not. In spite of this, however, the variation of the voltage in relation to the variation of current is not very different in the two cases. This is probably due to the rapidity with which the load changes, for there is no doubt that if the current varies slowly enough the effect of the compound winding is felt, some trouble having been experienced in working the sub-stations in parallel. The effect of the compound windings is very much the same as would arise if compound direct current generators were worked in parallel without any equalising connection; the division of the load between adjacent generators or sub-stations is liable to be unstable, and in the case of the Metropolitan District sub-stations reverse current cut-outs were constantly tripping the circuit breakers and disconnecting the rotaries from the bus-bars. For this reason the series field windings are not used in some sub-stations.

CHAPTER 21.

FIRST COSTS OF ELECTRIC TRAMWAYS, &c.

General remarks. Information as to costs of apparatus is undoubtedly of great value to those who know how to use it; but in inexperienced hands such knowledge is a dangerous weapon. In general, it may be said that the figures given in this and succeeding chapters should be used only for approximate estimates, and for purposes of a check on rough calculations.

Prices vary so much in different cases, and depend so largely on special circumstances that great discretion is required in arguing from one installation already in existence to another in the future. There are, further, many reasons why the price of any article may be different on two occasions, although the purposes to which it is to be applied are identical. For instance, the costs of raw material vary greatly, as also the methods of manufacture and consequently the labour involved. Similarly competition may increase or diminish and with it the margin for profit, commercial expenses, etc. These causes of variation operate gradually, and for short periods may be safely predicted by those who keep in touch with such matters. But the applicability of any precedent is more difficult to judge and requires wide expert knowledge.

Installation of electric tramways.

1. Inclusive prices:

   (*a*) Track, per mile of single track including special work from £5200.

[Examples*. Cost per mile of single track, new material throughout :

Leeds	£5613.
Liverpool	£5800.
Sheffield	£5980.
Manchester	£5970.
Glasgow	£5651.
East Ham	£6562.]

* *Tramway and Railway World*, June 11, 1903.

(*b*) Overhead construction:

Per mile of single track with single poles and side brackets from about £600.

Per mile of double track with side poles and span wire construction from about £1200.

Per mile of double track with centre pole construction from about £1000.

(*c*) Electrically equipped tramcars from about £470.

[Examples*:

(Nov. 1903) Preston, 30 cars at £472.
(Oct. 1903) Brighton, 20 cars at £501.
(Feb. 1904) Southend, 5 bogie cars at £602.
(July, 1904) Salford, 10 single truck double deck cars at £580.
10 double truck combination cars at £697.]

2. Detailed prices.

Track rails, fish plates, bolts and nuts and tie bars.

Rails from about ... ... per ton £5 10 0

Examples:

Southampton (June, 1904),					
rails, fish plates and anchor joints ...	per ton	£5	9	6
tie bars	,,	£9	0	0
bolts and nuts	,,	£16	2	6
Leeds Corporation (Dec. 1904), rails ...	,,	£5	7	6
London County Council (Dec. 1903), rails ...	,,	£5	16	6
Bradford (Feb. 1904), rails	,,	£5	13	11
fish plates	,,	£7	3	11

Sheffield †,

	per yard of single track	per ton
rails	£0 16 10·5	£8 15 0
fish plates	£0 1 3	£8 15 0
bolts	£0 0 5·8	£16 0 0
tie bars	£0 0 4·7	£10 10 0
copper bonds	£0 1 9·3	
plastering and packing rails ...	£0 1 6	
labour	£0 2 6	
	£1 4 10	

Special work.

Southampton (June, 1904), per pair of points (Hadfield) £27 10 0
crossing ,, £12 10 0

Bonds.

The price of copper bonds depends on the price of copper which is subject to great variations.

* Extracts from *Electrician*, Tenders received and accepted.
† *Street Railway Journal*, Feb. 15, 1904.

Welded rail joints*.

Electrically welded joints \$6.00 per joint for not less than 3000.
Thermit welded joints \$4.50 per joint } plus \$1.25 for opening
Cast welded joints \$2.75 per joint } and closing street.

Approximate analysis of cost of permanent way. Per mile of single track:

Rails—100 lbs. per yard at £6 per ton	£944
Crossings, points, fish plates, ties, etc., add about 30 per cent.	£282
Copper bonds (including cross bonds) about	£120
Excavation of roadway, 9 feet by 14 inches, at 4/6 per cubic yard	£463
Supplying and laying concrete at 15/- per cubic yard, 9 feet by 6 inches	£660
Laying rails, including jointing and bonding, at 2/- per yard of single track	£176
Material and labour for paving with new granite setts at 14/- per sq. yard	£3080
Sundries, drain boxes, reinstatement of macadam, etc.	£300
Total per mile of single track	£6025

Permanent way construction. The following schedule may be useful as a rough guide in estimating the cost of permanent way construction for electric tramways. Notes are given below with regard to the work and materials involved.

Description	Unit	Price £	s.	d.
Excavations in roads and car shed approach	per cub. yd.	0	3	7
Platelaying, including bending rails for curves in the road, adjusting to level, bolting and riveting fish and anchor plates, but not laying points and crossings (cartage included)	per yd. run of single track	0	1	5
Platelaying in car sheds, rails spiked to timber	per yd. of single track	0	1	6
Laying points and crossings, rails ready bent under another contract	per sett	3	6	0
Concrete and ramming under rails ...	per cub. yd.	0	15	6
Floating surface of concrete to flanges of rails	per sq. yd.	0	0	4
Parging sides of rails	per yd. run	0	0	3
Sand and cement bed for setts	per sq. yd.	0	0	4
Laying basaltic lava setts as edging to rails 6″, 9″ and 1′ 6″ wide, and grouting as specified	,,	0	2	9

* *Street Railway Journal*, Sept. 30, 1905, p. 583.

Description	Unit	Price £ s. d.
Laying basaltic lava setts between rails, including cutting to fit rails and tie bars, and grouting as specified (carting included)	per sq. yd.	0 2 9
Laying granite setts as edging to rails 1′ 6″ wide, and grouting as specified...	"	0 2 9
New macadam $3\frac{1}{2}''$ deep laid between rails	"	0 1 6
Fixing drain boxes to rails, including drilling and cutting same, and connecting to nearest surface water drain (say 20 yards) by earthenware piping as specified laid to falls and properly jointed	each	2 14 0
Earthenware pipes (type A) laid in or under concrete bed as may be directed	per yd. run	0 1 9
Fencing, watching, water and lighting, attendance	per yd. run of roadway	0 0 9

Notes on the above schedule:

Cement to be Portland of British manufacture; to pass through a sieve of 1600 meshes per square inch with residue of 5 per cent. on a sieve of 2500 meshes per square inch.

Ballast used for concrete must be of such a size as to pass through a $1\frac{1}{2}''$ ring.

Concrete to be gauged in proportion of one of cement to six of ballast and sand together by volume.

Cement mortar for parging the rails and grouting the setts to be one part cement to three parts sand.

Rails weighing 90 lbs. per yard, in 45 foot lengths.

Sole or "anchor" plates will be delivered with drilled holes $\frac{13}{16}$ inch diameter.

Top of concrete bed to be raised half an inch above the sole of the rail by floating with fine concrete (one of cement to four of sand).

Paving to be of two classes (*a*) edging rails with setts 9″ and 6″ respectively with macadam between the rails, (*b*) paving with setts between the rails and a margin of 18″ on each side. In class (*a*) the space in the centre of the track to be made up with macadam at least $3\frac{1}{2}$ inches deep, the bed of hard core being suitably prepared.

Overhead construction. A similar schedule dealing with overhead construction may also be useful for estimating purposes; it is important, however, to note that the prices were prepared in the later half of 1902, since when the prices of raw materials have altered considerably, and in making use of the figures proper allowance must be made for this.

Description	Unit	Price £	s.	d.
"A" type poles, delivered and erected complete with the exception of bases, including excavation, concrete bases, setting, reinstatement, making good pavement, and painting	each	7	11	4
"B" type poles, etc.	"	9	15	0
"C" type poles, etc.	"	19	6	6
No. 1 pattern bases of "A" type poles, delivered fixed and painted	"	0	3	9
No. 2 ditto for "A" type poles, ditto ...	"	0	16	8
No. 1 " "B" " ...	"	0	4	11
No. 2 " "B" " ...	"	0	18	10
No. 1 " "C" " ...	"	0	5	11½
No. 2 " "C" " ...	"	1	12	3
Bracket arms 10 feet long, delivered fixed and painted, complete	"	2	4	4
Ditto 12 feet long, ditto	"	2	5	8
" 14 " "	"	2	9	11
" 16 " "	"	2	12	9
Feeder pillar, erected complete and painted	"	6	2	0
Feeder pillar accessories, fitted complete, including section insulators, as specified	"	12	18	0
Wiring between feeder pillars and trolley wires (average distance of feeder pillar from trolley pole 6 feet) including earthing feeder pillar, cable and materials, all as specified and all fixing, except cost of trenching and reinstatement ...	per pillar	9	14	7
Yards of double trolley wire, delivered and erected, including supply and erection of all hangers, ears, frogs, pull-offs, terminals, etc. all as specified, together with all necessary strain and anchor wires...	per 100 yds.	8	9	8
Yards of single trolley wire in depôt and car shed, including wood troughing in car shed, erected complete as specified	"	21	10	0
Span wires, lengths as found necessary, with all necessary insulators, turn-buckles, etc. erected complete as specified......	each	0	12	5
Wood troughing under railway bridge, erected complete as specified...........	per foot	0	1	7
Guard wire, erected complete in lengths as required with all attachments ...	per 100 yds. of route	2	13	9
Earthing connections and attachments for guard wires as specified	per pole	0	10	9
Telephones (six in feeder pillars, one in power house, and one in car shed), complete with battery and connected up to cables supplied and laid under another contract	each	6	19	9

Notes on the above schedule. Poles—mild steel tubes in three sections; total length 31 feet; tubes to be lap welded with welds 120° apart; pedestal of base not less than 3 ft. 6 ins. high; three types A, B and C as follows:

	Inside diameter and minimum thickness		
	A	B	C
Bottom section	7″—·40″	8″—·50″	10″—·75″
Middle section	6″—·30″	7″—·40″	9″—·60″
Top section	5″—·25″	6″—·30″	8″—·50″
Minimum load to be borne with 6″ deflection ...	1000 lbs.	1700 lbs.	3500 lbs. with 4″ deflection

All poles to be sunk 6 feet in the ground, in the centre of a concrete column to at least 6″ below bottom of pole; diameters of concrete columns as follows A 20″, B 24″, C 7 feet deep and 36″ square.

Brackets—to consist of 2″ steel pipe not less than ¼″ thick; to be supported by scroll work for lengths up to 7 feet; for brackets from 7 feet to 12 feet scroll work to be supplemented by a ⅜″ tie rod; for brackets from 12 feet to 16 feet by two tie rods.

Span wires—for supporting trolley wires to be 7/14 S.W.G. galvanized steel wires with breaking load not less than 4500 lbs.; for supporting guard wires 7/17 S.W.G. Spans to be so tightened that stress in coldest weather shall not exceed one-fourth of the breaking strain.

Suspension insulators and ears—insulators to stand 2000 volts alternating for half an hour after having been soaked for seven days and then dried. Ears to be bronze, 15″ long on the straight and 24″ long on curves, trolley wire to be soldered in.

Trolley wire—of diameter ·324 inch, with breaking load not less than 4000 lbs.; to be supplied in half-mile lengths on drums; trolley to be run double throughout over single and double track; over a single track the wires to be not less than 8″ apart.

Feeder pillars—to contain a slate panel with four quick-break single pole 100-ampere switches, one lightning arrester, terminals for telephone instrument and pilot wires; to be waterproof but ventilated; to have locked doors back and front; to be erected on a bed of concrete 6″ thick and earthed to rail by a ·083 square inch cable; to be connected to trolley wires by cables having a section of ·06 sq. in.

rubber covered and braided 2500 megohm class; four separate cables to be laid from each pillar one to each side of each section insulator; to be laid in separate iron pipes from the pillar to the nearest pole.

Insulation resistance of line to earth after erection to be at least 100000 ohms per mile of single trolley including feeder pillar connections.

Telephones—to consist of magneto bell, receiver and transmitter.

Other systems.

Conduit systems.

*London County Council Tramways. Reconstruction:
16·4 miles of single track at an average price per mile of £13600
(including £800 per mile for diverting pipes, etc.)
*American tramways:
in outlying districts per single mile £15200
in central urban districts per single mile ... £21200

Surface contact systems.

Griffiths-Bedell system:

Cost for three miles of single track at Lincoln ... £24000

[NOTE. This price would probably hold good for three miles of straightforward single track, including the supply of all road material; at Lincoln there is a good deal of special work; but some of the old granite setts were redressed and relaid.]

Electric tramcars.

Car bodies, trucks and equipments.

Leyton—40 car bodies at £310,
40 Mountain and Gibson radial trucks at £91. 14*s.* (about),
40 electrical equipments at £280. 6*s.* (about),
Gloucester (Dec. 1903)—10 equipments at £176,
10 car bodies at £268.

Miscellaneous.

Salford (Nov. 1903)—for covering top deck £92.

Total capital cost. As an example of the total capital cost of a large tramway system, the case of the Glasgow Corporation Tramways may be taken†.

The number of cars in stock is 783, and the total length of lines open for traffic is 160¾ miles of single track.

* Report by Messrs Fitzmaurice and Baker, see *Tramway and Railway World*, June 11, 1903; see also *Engineering*, June 1, 1906, p. 723, giving price of £26538 for mile of double track on the extension to Highbury.

† *Electrician*, August 3, 1906, p. 624.

Account	Expenditure to May 31, 1906	Per cent. of total
Permanent way	£905,990	30·4
Electrical equipment of line	587,870	19·8
Land	136,222	4·6
Buildings, etc.	426,122	14·3
Generating plant	388,036	13·1
Workshop, tools and plant	25,814	·9
Cars	264,232	8·9
Electrical equipment of cars	195,275	6·6
Other rolling stock	7,576	·3
Miscellaneous equipment	18,090	·6
Office furniture	5,163	·2
Lease of Govan and Ibrox tramways	4,057	·1
Parliamentary expenses	6,902	·2
Total	£2,971,349	100·0

CHAPTER 22.

RECEIPTS, WORKING EXPENSES AND TRAMWAY ACCOUNTS IN GENERAL.

General remarks. A great deal of information as to the financial results of electric tramway undertakings has been published in the technical press, to which reference should be made for detailed information. In particular, the *Electrical Times* publishes every week a table giving full information as to the financial position of a large number of tramway systems, with traffic records, costs per kw.h. and operating costs per car mile.

The subject may be considered under the following headings: 1. Capital cost. 2. Revenue. 3. Operating costs. 4. Financial results.

1. Capital cost. This has been referred to already in the previous chapter, but general considerations may be touched upon here. The capital cost will include expenditure on track and overhead or other distributing system, cars, feeders, generating and sub-stations, car sheds and offices. The bases on which estimates are prepared are, naturally, the magnitude of the population to be served and the nature of the district. A careful consideration of these factors is necessary before deciding on the routes to be provided; the decision being made, an estimate can be formed of the first cost of the track and the distributing system. The number of cars required bears a more direct relation to the population. For moderate sized towns the car miles per annum are in most cases between 8 and 10 times the population; in a few very large cities, such as Leeds, Bradford, Glasgow, Liverpool and Manchester the ratio is higher, varying between 15·6 and 18·8. The miles per annum covered by a single car are about 20000 on the average.

If then the number of car miles be determined, the number of cars required on the system may be obtained by dividing this number by 20000. If, further, a certain proportion of this number be supposed to be spares, an approximate idea may be obtained of the capacity of the generating station.

The question of feeders cannot be decided by mere statistics as it depends on so many considerations.

2. Revenue. A glance at the *Electrical Times* table of electric tramway costs and records will shew that the traffic revenue per car

mile is in the large majority of cases very close to 10*d*. As a general rule it may be taken that if the earnings amount to less than 9*d*. per car mile, there will be a deficit instead of a surplus as the result of the year's working.

3. Operating costs. The operating cost consists of the following items:

(*a*) Cost of power.

(*b*) Traffic costs, including wages of drivers, conductors and inspectors.

(*c*) Repairs and maintenance, including track, distribution, feeders, cars and buildings.

(*d*) Management, including office expenses, etc.

(*a*) In the majority of cases power is purchased by the tramway undertaking, but in a few cases generating stations have been supplied for the tramways alone. When power is purchased the price per unit is generally about $1\frac{1}{2}d.$; a few examples will shew this:

	Price per unit, pence
Halifax	1·5
Manchester	1·49
Burton	1·39
Bradford	1·03
Brighton	1·50
Bolton	1·10
Lancaster	1·94
Oldham	1·50
Stockport	·89
Sunderland	1·75

When the tramway system undertakes its own supply the works cost is a good deal lower than most of the above figures, but against this saving must be put annual charges for interest on capital outlay and amortisation. Table 23 shews the details of the works costs for local authorities who have separate generating stations for traction.

In tramway accounts the cost of power is given in terms of pence per car mile. Now the energy consumed per car mile varies according to the size of the cars, the character of the routes whether hilly or flat, and the average speed. For small cars in a flat locality the energy consumption per car mile is about 1·1 units, corresponding to an average of $7\frac{1}{2}$ kw. per car, an average speed of 8 miles per hour, and about 4 per cent. loss in distribution. For heavy cars and higher speeds the energy consumption is greater; for instance, in Salford, where there are a number of heavy bogie cars with covered top decks, the energy consumption is 1·42 units per car mile. In Sheffield, where the grades are steep, the worst being 1 in 9·5, the figure is 1·72. In Nottingham, where there are 89 single truck cars and 16 double bogie cars, and the steepest gradient is 1 in 11·5, the consumption is 1·57.

TABLE 23. *Details of works costs for local authorities who have separate generating stations for traction.*

Place	Year ended March	Number of units used	Pence per unit				
			Coal and other fuel	Oil waste water stores	Wages and salaries	Repairs and maintenance	Total works cost
Birkenhead	1905	2,276,901	·29	·05	·20	·06	·60
Glasgow	(May) 1905	20,268,407	·12	·02	·11	·05	·3
Huddersfield	1906	3,305,889	·17	·01	·10	·08	·36
Hull	1905	3,853,114	·26	·03	·09	·08	·46
Leeds	1905	11,503,188	·16	·03	·07	·03	·29
Leicester	1905	4,975,600	·16	·04	·12	·02	·34
Northampton	1906	829,461	·27	·08	·24	·08	·67
Portsmouth	1905	3,019,995	·33	·06	·11	·04	·54
Reading	1905	1,020,400	·43	·03	·25	·04	·75
Sheffield	1905	10,781,227	·20	·04	·08	·13	·45

In a few cases the system is sufficiently extensive to require sub-stations; if, in these cases, the works cost is reckoned on the basis of the number of units supplied by the generating station, an allowance must be made for losses in the high tension cables and the sub-stations.

(*b*) Traffic costs.

The chief item in the traffic costs is the wages of drivers and conductors. These vary a good deal according to the locality, but average figures seem to be about 7*d.* per hour for drivers and 5*d.* per hour conductors. If each car travels 7 miles in the hour, at this rate of wages the cost would be 1·71 pence per car mile. In addition to this there are the wages of the inspectors and of spare men and the traffic staff, which generally bring up the wages item to about 2·2 pence per car mile.

Other items included in the traffic costs are shewn by an example (Manchester Corporation Tramways).

Item	Pence per car mile 1902–3	Pence per car mile 1903–4
Salaries, wages of drivers, guards and traffic staff	2·27	2·35
Cleaning and oiling cars	·32	·29
Cleaning and sanding track	·06	·06
Ticket and cash counting departments	·27	·22
Depôt expenses	·25	·21
Miscellaneous	·36	·28
Total	3·53	3·41

(c) Repairs and maintenance of track, overhead system and feeders, cars and buildings.

A few examples from published records* are given in Table 24 and will shew how these items vary.

TABLE 24. *Maintenance costs for several tramway systems.*

Place	Pence per car mile				
	Rolling stock	Permanent way	Overhead equipment	Buildings	Total
Manchester Corp. (1903–4)	·57	·19	·09	·01	·86
East Ham (1902–3)	·66	·12	·05	·05 (sundries)	·88
Bradford (1902–3)	1·49	·34	·10	—	1·93
Sheffield (1902–3)	·4	·18	·24	·03	·85
Glasgow (1903–4)	·44	1·30	·10		
Hull (1903–4)	1·40	·15	·24		
Birkenhead (1903–4)	·25	·44	·13		
Wallasey (1903–4)	·62	·09	·27		

(d) Management expenses.

These vary considerably, but seldom amount to more than 1*d*. per car mile. The average of a large number of cases is about ·8*d*., and for some systems it is as low as ·5*d*.

Total operating costs thus come to about 6*d*. per car mile, varying between fairly wide limits.

4. **Financial results.** The difference between the operating costs and the revenue represents the gross profit, from which interest on capital is drawn, and any charges for a reserve fund or a sinking fund. The interest on the borrowed capital requires no comment, the rate of interest being agreed upon at the time of borrowing. The other charges on the gross profit depend partly upon the status of the authority owning the tramway. If the authority be a public company the question of a reserve fund is one which rests with the Board of Directors. If, however, the tramway is owned by a Local Authority, which borrows the capital on the security of the rates, the permission of the Local Government Board is necessary before the Local Authority may borrow the capital, and the condition is always laid down that a sinking fund is to be instituted, to which there shall be an annual contribution from the gross profit of such an amount that the total

* *Electrical Review*, vols. 54, 55.

capital may be repaid in a certain number of years. This period of repayment varies for different systems, in some cases being 25 years, in others 30.

In addition to these charges on the gross profit the Local Authority is sometimes permitted to provide a reserve fund, if they think fit, limited in amount to one-fifth of the aggregate capital expenditure. This reserve fund may be drawn on from time to time for any special expenditure in connection with the working of the undertaking, and in many cases this fund is put aside specially for meeting the calls due to depreciation. These calls are, of course, apart from the normal charges for maintenance, being intended to apply to comparatively large outlays from time to time due to the plant becoming obsolete or requiring renewal on a large scale.

This reserve fund may accumulate at compound interest until it reaches the prescribed limits, after which the interest, together with any net surplus, is to be devoted to the relief of the rates or improvement of the district or reduction of borrowed capital.

Working expenses of surface contact systems. The following figures are taken from a Report of the Tramway's Committee to the Council in connection with the Wolverhampton Corporation Tramway's undertaking, dated June 27, 1905. The first column of figures refers to the Lorain surface contact system.

	Wolverhampton	Average of 39 undertakings
Percentage of costs to revenue ...	59·3	66
Percentage of gross profit to average capital	6·9	6·08
Passengers per car mile	9·4	8·9
Journeys per head of population per annum	80	80
Revenue per car mile	10·898*d.*	9·75*d.*
Average fare	1·15*d.*	1·12*d.*
Total operating costs per passenger ...	·69*d.*	·78*d.*
Units per car mile	1·58	1·34
Repairs and maintenance per car mile (including electrical equipment) ...	·844*d.*	1·03*d.*
Management	·77*d.*	·92*d.*
Total operating costs per car mile* ...	6·55*d.*	6·75*d.*

* The report dated July 2, 1906, gives 6·13*d.* as compared with 6·56*d.*, the average of 55 undertakings.

APPENDIX.

BOARD OF TRADE REGULATIONS, PROCEDURE, ETC.

(1) Tramways and Light Railways.

The regulation of Electric Tramways in this country is in the hands of the Board of Trade, whereas Electric Light Railways in connection with mines come under the control of the Home Office.

The Regulations of the Board of Trade in connection with Electric Tramways may be divided into two classes, viz. those that deal with tramways in general, and those that are concerned with particular undertakings. The former, which are given at length below, include (*a*) a model description of Electrical Equipment (on the overhead trolley system) of Tramways or Light Railways laid on public roads; this is intended as a guide to promoters (p. 435); (*b*) a memorandum regarding details of construction and equipment of new lines; this deals with various points in connection with clearance, posts and brackets, permanent way and cars (p. 436); (*c*) a special memorandum on guard wires on Electric Tramways (p. 438); (*d*) Protective Regulations, which consist of a set of rules drawn up for the protection of owners of water pipes, and others who might be affected injuriously by the working of the Tramways (p. 442).

In the second class are those regulations which are drawn up for each particular case, being a set of Protective Regulations (generally almost identical with those referred to above), and a set of working regulations which deal with the carrying on of the undertaking and provide specific instructions as to the limits of speed, the number of stopping places and other details. As an example of working regulations a copy of those drawn up for the Newcastle-upon-Tyne Corporation Tramways, is given below in an abbreviated form (p. 448).

In relation to Light Railways in connection with Mines a few extracts are given below from the Home Office Regulations with regard to the use of Electricity in Mines (p. 452).

(2) Railways.

Not much information can be given as to the requirements of the Board of Trade in the case of Electric Railways, but the following may be consulted:

(α) The Railways (Electrical Power) Act, 1903, Ch. 30, facilitates the introduction and use of Electrical Power on Railways. Under it the Board of Trade may, upon the application of a Railway Company, make certain orders. The position of the Board of Trade in this connection is difficult to define in the case of Railways employing an insulated return, but in connection with new Railways the question would be settled by Act of Parliament. (p. 453.)

(β) In the case of Railways constructed underground in metal-lined tunnels (Tube Railways) Regulations have been prescribed by the Board of Trade to correspond with the "Protective Regulations" for Tramways and Light Railways. With the exception of the City and South London, the Waterloo and City, and the Central London Railways, the Tube Railways of London employ an insulated return. When an insulated return is employed these Regulations may be regarded more in the light of Recommendations. (p. 456.)

(γ) Requirements of the Board of Trade in regard to the precautions to be taken against the risk of Accident by Fire on underground Electric Railways. (p. 459.)

BOARD OF TRADE. MARCH, 1905.

MODEL DESCRIPTION OF ELECTRICAL EQUIPMENT (ON THE OVERHEAD TROLLEY SYSTEM) OF TRAMWAYS OR LIGHT RAILWAYS LAID ON PUBLIC ROADS.

NOTE.—*This model should be retained for reference. It is intended to shew the amount of detail required, and not to suggest actual details. A description should be drawn up following the model as closely as circumstances permit.*

Power will be supplied at from 500 to 550 volts through underground feeders to hard drawn trolley wires   S.W.G.

The feeders will be lead-covered, laid in troughing filled in solid with composition and covered with hard burned tiles or other suitable protection, or will be drawn into earthenware ducts.

Detachable swivel trolley heads will be used, and the trolley wire will be in general at a height of about 21 feet, and at a distance horizontally of from 4 to 5 feet from the centre of the track.

The trolley wires will be flexibly suspended from brackets fixed to tubular poles, or in some cases from span wires fastened to poles or to the walls of houses by suitable means, and in such a way as to provide

for double insulation throughout between the trolley wires and earth. The bracket arms will have an average length of feet, and will in no case exceed feet in length.

Section switches will be provided at every half mile, either in pillar boxes or in boxes attached to the poles or to houses. Feeder switches will be provided in pillar boxes, and all pillar boxes will be arranged to prevent explosion of gas accumulating in them or in ducts connected with them.

The accompanying plan on a scale of six inches to one mile gives a diagram of the feeders, feeding points, return feeders, earthplates, and pilot wire points.

BOARD OF TRADE. February, 1906.

Tramways and Light Railways laid on Public Roads.

Memorandum regarding details of Construction and Equipment of New Lines.

(1) *Clearance.*

The space between the inner rails of a double line must depend upon the overhang of the cars. It is, however, necessary that there should be at least 15 inches between the sides of passing cars and also a similar space between the side of a car and any standing work such as lamp, telegraph and trolley wire posts in a street.

There should be at least 15 inches between the side of a car and the kerb, whether on straight or curved roads.

The clearance between the top deck of cars and the underside of bridges should not, if possible, be less than 6 feet 6 inches. Where this clearance cannot be obtained special precautions in working will be required, but in no case will less than 6 feet be accepted.

(2) *Posts and Brackets.*

Centre posts should not be used without the consent, in every case, of the Board of Trade.

The stone kerbing round centre posts should not be such as to enable any person to stand upon it as a refuge, unless the clearance is ample for safety.

Where bracket arms 16 feet in length will not suffice, it is desirable that span wire construction should be used.

(3) *Permanent way.*

The weight of rails should not be less than 90 lbs. per yard, 100 lbs. being preferred.

The groove of the rail should not exceed *one and an eighth inch* in width, but a groove not exceeding *one and a quarter inch* will be accepted on curves of less than 150 feet radius.

The details of permanent way and mode of construction as approved by the Board of Trade should not be varied at any time without the Board's consent.

(4) *Cars.*

Drawings of the cars intended to be used on a line should be submitted to the Board of Trade for approval, before orders for the cars are placed.

Staircases of the "reversed" type should be avoided, more especially on narrow gauge lines.

Of existing types the "trigger" lifeguard is the pattern which is preferred. The hanging gate should be as close to the ground as possible, and there should be at least 3 feet between it and the front of the guard. Both the guard and the gate should be at least as wide as the outside of the frame of the truck.

In order not to interfere with the efficiency of the lifeguard it is desirable that folding steps should be adopted on all new cars.

Where the gauge of the line is 3 feet 6 inches or less top deck covers should not be used without first communicating with the Board of Trade, to enable the circumstances of each such case to be specially considered.

Arrangements for sanding each rail may be required at each end of the cars where considered necessary on account of the gradient.

Top deck railings should be at least 3 feet 6 inches high.

All railings should be connected with earth.

The trolley standard must be connected with earth by a low resistance fuse or automatic switch, and the warning signal, when the fuse or switch opens, should be an electric bell.

Where trolley ropes cannot be dispensed with or tied up, precautions must be taken to prevent the "slack" causing accidents.

To prevent trolley booms being pulled out or trolley standards broken "traps" should be minimised and detachable trolley heads provided.

No material alterations should be made in cars after inspection, nor any fresh type of car adopted, without the consent of the Board of Trade.

BOARD OF TRADE. May, 1905.

Guard Wires on Electric Tramways.

Regulation.

If and whenever telegraph or telephone wires, unprotected with a permanent insulating covering, cross above, or are liable to fall upon, or to be blown on to, the overhead conductors of the tramways, efficient guard wires shall be erected and maintained at all such places.

EXPLANATORY MEMORANDUM.

Note.—The expression "telegraph wire" includes all telegraph and telephone wires.

For the purpose of this memorandum, telegraph wires are divided into two classes, namely:

(*a*) Wires weighing less than 100 lbs. per mile.

(*b*) Wires weighing 100 lbs. or more per mile.

Each guard wire should be well earthed at one point at least, and at intervals of not more than five spans. The resistance to earth should be sufficiently low to insure that a telegraph or telephone wire falling on and making contact with the guard wire and the trolley wire at any time will cause the circuit breaker protecting that section to open.

The earth connection should be made by connecting the wire through the support to the rails by means of a copper bond. When first erected, the resistance to earth of the guard wires should be tested, and periodical tests should be made to prove that the earth connection is efficient.

Guard wires should be, in general, of galvanised steel, but in manufacturing districts in which such wires are liable to corrosion bronze or hard drawn copper wires should be used.

The gauge of the guard wire should not be less than seven strands of No. 16 or one of No. 8 wire.

The supports for the guard wires should be rigid and of sufficient strength for their purpose, and at each support each guard wire should be securely bound in or terminated.

The rise of the trolley boom should be so limited that if the trolley leaves the wire it will not foul the guard wires.

Telegraph Wires crossing Trolley Wires.

Class (a).—Wires weighing less than 100 *lbs. per Mile.*

The guard wires may be of the cradle or hammock type, attached to the arms of telegraph poles. It is necessary that the spans should be short; and if required an additional pole or poles should be set.

(1) Where there is one trolley wire, two guard wires should be erected (figure 1).

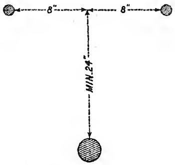


Fig. 1.

(2) Where there are two trolley wires at a distance not exceeding 12 feet apart, two guard wires should be erected (figure 2).

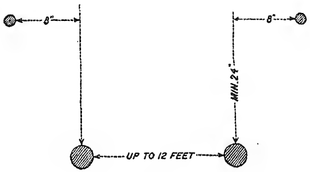


Fig. 2.

(3) In special cases, at junctions or curves, where parallel guard wiring would be complicated, two guard wires only will generally suffice if so erected that a falling wire must fall on them before it can fall on the trolley wire.

Class (b).—Wires weighing 100 *lbs. or more per Mile.*

(4) Where there is only one trolley wire, two guard wires should be erected (figure 3).

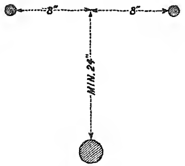


Fig. 3.

(5) Where there are two trolley wires not more than 15 inches apart, two guard wires should be erected (figure 4).

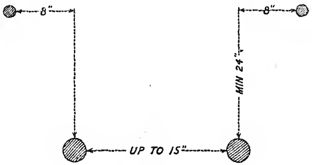


Fig. 4.

(6) Where there are two trolley wires and the distance between them exceeds 15 inches, but does not exceed 48 inches, three guard wires should be erected (figure 5).

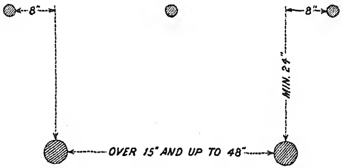


Fig. 5.

(7) Where the distance between the two trolley wires exceeds 48 inches, each trolley wire should be separately guarded (figure 6).

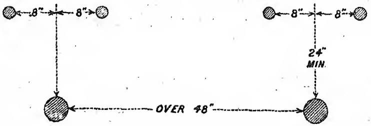


Fig. 6.

(8) It is desirable, where possible, to divert telegraph wires from above trolley junctions and trolley wire crossings, and undertakers should endeavour to make arrangements to that effect with the owners of telegraph wires.

TELEGRAPH WIRES PARALLEL TO TROLLEY WIRES.

Classes (a) and (b).

(9) Where telegraph wires not crossing a trolley wire are liable to fall upon or to be blown on to a trolley wire, a guard wire should be so erected that a falling wire must fall on the guard wire before it can fall on the trolley wire.

If the trolley wire is enclosed within a triangle formed by the vertical plane of a telegraph wire, and an imaginary line drawn at an angle of 45° from the uppermost telegraph wire on the side nearest to the trolley wire, a guard wire should be erected on span wires or on the brackets. This indicates the minimum requirements. In very exposed situations or for heavy routes of wires, more than one guard wire may be needed.

(10) When guard wires are attached to other supports than the trolley poles they should be connected with the rails at one point at least.

(11) When it is possible that a telegraph wire may fall on an arm or a stay, or a span wire, and so slide down on to a trolley wire, guard hooks should be provided.

GENERAL.

(12) Minimum guarding requirements for Classes (a) and (b) are provided for in this memorandum, but in exceptional cases, such as in very exposed positions, or for unusually heavy telegraph wires, special precautions should be taken.

Regulations* made by the Board of Trade under the provisions of Special Tramways Acts or Light Railway Orders authorising lines on public roads; for regulating the use of electrical power; for preventing fusion or injurious electrolytic action of or on gas or water pipes or other metallic pipes, structures, or substances; and for minimising as far as is reasonably practicable injurious interference with the electric wires, lines, and apparatus of parties other than the Company, and the currents therein, whether such lines do or do not use the earth as a return.

FIRST MADE, MARCH, 1894.
REVISED, APRIL, 1903.
FURTHER REVISED, AUGUST, 1904.

Definitions.

In the following regulations:

The expression "energy" means electrical energy.

The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy.

The expression "motor" means any electric motor carried on a car and used for the conversion of energy.

The expression "pipe" means any gas or water pipe or other metallic pipe, structure, or substance.

The expression "wire" means any wire or apparatus used for telegraphic, telephonic, electrical signalling, or other similar purposes.

The expression "current" means an electric current exceeding one thousandth part of one ampere.

The expression "the Company" has the same meaning as in the Tramways Act [Light Railways Order].

Regulations.

1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation†.

2. One of the two conductors used for transmitting energy from the generator to the motors shall be in every case insulated from earth, and is hereinafter referred to as the "line"; the other may be insulated

* The footnotes to these Regulations are inserted by the authors.
† This regulation is now practically obsolete.

throughout, or may be uninsulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return*."

3. Where any rails on which cars run or any conductors laid between or within three feet of such rails form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in Regulation 7*.

4. When any uninsulated conductor laid between or within three feet of the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity*.

5. (*a*) When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current-indicator hereinafter mentioned, to two separate earth connections which shall be placed not less than 20 yards apart.

(*b*) The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that an electromotive force, not exceeding four volts†, shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

(*c*) Provided that in place of such two earth connections the Company may make one connection to a main for water supply of not less than three inches internal diameter, with the consent of the owner thereof and of the person supplying the water, and provided that where, from the nature of the soil or for other reasons, the Company can shew to the satisfaction of an inspecting officer of the Board of Trade that the earth connections herein specified cannot be constructed and maintained without undue expense the provisions of this regulation shall not apply.

(*d*) No portion of either earth connection shall be placed within six feet of any pipe except a main for water supply of not less than three inches internal diameter which is metallically connected to the earth connections with the consents hereinbefore specified.

* These regulations are now practically obsolete.

† This E.M.F. should be produced by a battery of low internal resistance. Lead storage cells are most suitable.

(*e*) When the generator is at a considerable distance from the tramway the uninsulated return shall be connected to the negative terminal of the generator by means of one or more insulated return conductors, and the generator shall have no other connection with earth; and in such case the end of each insulated return connected with the uninsulated return shall be connected also through a current indicator to two separate earth connections, or with the necessary consents to a main for water supply, or with the like consents to both in the manner prescribed in this regulation.

(*f*) If the current indicator cannot conveniently be placed at the connection of the uninsulated return with the insulated return, this instrument may consist of an indicator at the generating station connected by insulated wires to the terminals of a resistance interposed between the return and the earth connection or connections*. The said resistance shall be such that the maximum current laid down in Regulation 6 (i) shall produce a difference of potential not exceeding one volt between the terminals. The indicator shall be so constructed as to indicate correctly the current passing through the resistance when connected to the terminals by the insulated wire before-mentioned.

6. When the return is partly or entirely uninsulated the Company shall in the construction and maintenance of the tramway (*a*) so separate the uninsulated return from the general mass of earth, and from any pipe in the vicinity; (*b*) so connect together the several lengths of the rails; (*c*) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point; and (*d*) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfil the following conditions, viz.:

(i) That the current passing from the earth connections through the indicator to the generator or through the resistance to the insulated return shall not at any time exceed either two amperes per mile of single tramway line or five per cent. of the total current output of the station.

(ii) That if at any time and at any place a test be made by connecting a galvanometer or other current-indicator to the uninsulated return and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanché cells connected in series if the direction of the current is

* A low resistance maximum demand indicator is now accepted.

from the return to the pipe, or by interposing one Leclanché cell if the direction of the current is from the pipe to the return.

In order to provide a continuous indication that the condition (i) is complied with, the Company shall place in a conspicuous position a suitable, properly connected, and correctly marked current-indicator, and shall keep it connected during the whole time that the line is charged.

The owner of any such pipe may require the Company to permit him at reasonable times and intervals to ascertain by test that the conditions specified in (ii) are complied with as regards his pipe.

7. When the return is partly or entirely uninsulated a continuous record shall be kept by the Company of the difference of potential during the working of the tramway between points on the uninsulated return. If at any time such difference of potential between any two points exceeds the limit of seven volts, the Company shall take immediate steps to reduce it below that limit.

8. The current density in the rails shall not exceed 9 amperes per square inch.

9. Every electrical connection with any pipe shall be so arranged as to admit of easy examination, and shall be tested by the Company at least once in every three months.

10. Every line and every insulated return or part of a return except any feeder shall be constructed in sections not exceeding one-half of a mile in length, and means shall be provided for isolating each such section for purposes of testing.

11. The insulation of the line and of the return when insulated, and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one-hundredth of an ampere* per mile of tramway. The leakage current shall be ascertained daily† before or after the hours of running when the line is fully charged. If at any time it should be found that the leakage current exceeds one-half* of an ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within 24 hours. Provided that where both line and return are placed within a conduit this regulation shall not apply.

* This may be modified to allow for surface leakage in the case of surface-contact systems.

† This regulation has been modified in recent cases to the effect that the leakage current shall be ascertained not less frequently than once a week.

12. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

13. Where in any case in any part of the tramway the line is erected overhead and the return is laid on or under the ground, and where any wires have been erected or laid before the construction of the tramway in the same or nearly the same direction as such part of the tramway, the Company shall, if required so to do by the owners of such wires or any of them, permit such owners to insert and maintain in the Company's line one or more induction-coils or other apparatus approved by the Company for the purpose of preventing disturbance by electric induction. In any case in which the Company withhold their approval of any such apparatus the owners may appeal to the Board of Trade, who may, if they think fit, dispense with such approval*.

14. Any insulated return shall be placed parallel to and at a distance not exceeding three feet from the line when the line and return are both erected overhead, or eighteen inches when they are both laid underground.

15. In the disposition, connections, and working of feeders, the Company shall take all reasonable precautions to avoid injurious interference with any existing wires.

16. The Company shall so construct and maintain their system as to secure good contact between the motors and the line and return respectively.

17. The Company shall adopt the best means available to prevent the occurrence of undue sparking at the rubbing or rolling contacts in any place and in the construction and use of their generator and motors.

18. Where the line or return or both are laid in a conduit the following conditions shall be complied with in the construction and maintenance of such conduit:

(*a*) The conduit shall be so constructed as to admit of examination of and access to the conductors contained therein and their insulators and supports.

(*b*) It shall be so constructed as to be readily cleared of accumulation of dust or other *débris*, and no such accumulation shall be permitted to remain.

* This regulation has since been cancelled.

(c) It shall be laid to such falls and so connected to sumps or other means of drainage, as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(d) If the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or other means of equal conductivity, at distances apart not exceeding 100 feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to earth at the generating station or sub-station through a high resistance galvanometer suitable for the indication of any contact or partial contact of either the line or the return with the conduit.

(e) If the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, the conductors shall be carried on insulators the supports for which shall be in metallic contact with one another throughout.

(f) The negative conductor shall be connected with earth at the station by a voltmeter and may also be connected with earth at the generating station or sub-station by an adjustable resistance and current-indicator. Neither conductor shall otherwise be permanently connected with earth.

(g) The conductors shall be constructed in sections not exceeding one-half a mile in length, and in the event of a leak occurring on either conductor that conductor shall at once be connected with the negative pole of the dynamo, and shall remain so connected until the leak can be removed.

(h) The leakage current shall be ascertained daily*, before or after the hours of running, when the line is fully charged, and if at any time it shall be found to exceed one ampere per mile of tramway the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within 24 hours.

* This record may now be taken weekly.

19. The Company shall, so far as may be applicable to their system of working, keep records as specified below. These records shall, if and when required, be forwarded for the information of the Board of Trade.

Daily Records.

No. of cars running.

No. of miles of single tramway line.

Maximum working current.

Maximum working pressure.

Maximum current from the earth plate or water-pipe connections (*vide* Regulation 6 (i)).

Leakage current (*vide* Regulations 11 and 18 (*h*))*.

Fall of potential in return (*vide* Regulation 7).

Monthly Records.

Condition of earth connections (*vide* Regulation 5).

Minimum insulation resistance of insulated cables in megohms per mile (*vide* Regulation 12).

Quarterly Records.

Conductance of joints to pipes (*vide* Regulation 9).

Occasional Records.

Specimens of tests made under provisions of Regulation 6 (ii).

TRAMWAY.

Regulations and Byelaws, dated 23rd May, 1905, made by the Board of Trade as regards Electrical Power (Overhead Trolley System) on the Newcastle-upon-Tyne Corporation Tramways.

The Board of Trade, under and by virtue of the powers conferred upon them in this behalf, do hereby make the following regulations for securing to the public reasonable protection against danger in the exercise of the powers conferred by Parliament with respect to the use of electrical power (overhead trolley system) on all or any of the tramways on which the use of mechanical power has been authorised by the Newcastle-upon-Tyne Improvement Act, 1882, Newcastle-upon-Tyne Improvements and Tramways Act, 1899, and the Newcastle-upon-Tyne Corporation Tramways Extension Act, 1902 (hereinafter called "the tramways"):

* This record may now be taken weekly.

And the Board of Trade do also hereby make the following byelaws with regard to all or any of such tramways worked by electrical power on the overhead trolley system.

The Order of the Board of Trade in this behalf, dated the 11th day of May, 1903, is hereby rescinded.

Regulations.

I. Every motor carriage used on the tramways shall comply with the following requirements, that is to say:

(*a*) It shall be fitted, if and when required by the Board of Trade, with an apparatus to indicate to the driver the speed at which it is running.

(*b*) The wheels shall be fitted with brake blocks, which can be applied by a screw or by other means, and there shall be in addition an adequate electric brake.

The carriages used on the Elswick Road and Westgate Road routes shall also be fitted with a slipper brake or other track brake approved by the Board of Trade for use on the Tramways.

(*c*) It shall be conspicuously numbered inside and outside.

(*d*) It shall be fitted with a suitable lifeguard, and with a special bell or whistle to be sounded as a warning when necessary.

(*e*) It shall be so constructed as to enable the driver to command the fullest possible view of the road.

II. No trailing carriage shall be used on the tramways except in the case of the removal of a disabled carriage.

III. Every carriage used on the tramways shall be so constructed as to provide for the safety of passengers, and for their safe entrance to, exit from, and accommodation in such carriage.

IV. Every carriage on the tramways shall, during the period between one hour after sunset and one hour before sunrise or during fog, carry a lamp so constructed and placed as to exhibit a white light visible within a reasonable distance to the front, and every such carriage shall carry a lamp so constructed and placed as to exhibit a red light visible within a reasonable distance to the rear.

V. The speed at which the carriages shall be driven or propelled along the tramways shall not exceed the rate of:

Fourteen miles an hour—

In Walker Road, between St Anthony's Church and St Peter's Road, &c.

Twelve miles an hour—

In Jesmond Road, between Sandyford Road and Osborne Road, etc.

Eight miles an hour—

In Pilgrim Street, from Market Street to City Road, on the descending journey, etc.

Six miles an hour—

(*a*) In Westmoreland Terrace, from George Street to Blandford Street, on the inward journey.

(*b*) On curve between Sandyford Road and Jesmond Road, etc.

Four miles an hour—

(*a*) Through facing points, whether fixed or moveable.

(*b*) On the curve between City Road and Pilgrim Street.

(*c*) When crossing the junction of Blackett Street, Pilgrim Street, Northumberland Street, and New Bridge Street, etc.

At all other places the speed shall not exceed the rate of *ten* miles an hour.

VI. The electrical pressure or difference of potential between the overhead conductors used in connection with the working of the tramways and the earth, or between any two such conductors, shall in no case exceed 550 volts. The electrical energy supplied through feeders shall not be generated at or transformed to a pressure higher than 650 volts, except with the written consent of the Board of Trade, and subject to such regulations and conditions as they may prescribe.

VII. The overhead conductors used in connection with the working of the tramways shall be securely attached to supports, the intervals between which shall not, except with the approval of the Board of Trade, exceed 120 feet, and they shall be in no part at a less height from the surface of the street than 17 feet, except where they pass under bridges.

VIII. The overhead conductors shall be divided up into sections not exceeding (except with the special approval of the Board of Trade) one-half of a mile in length, between every two of which shall be inserted an emergency switch so enclosed as to be inaccessible to pedestrians.

IX. Each separate insulator on the overhead conductors shall be tested not less frequently than once in a month, and any insulator found to be defective shall at once be removed and an efficient insulator substituted.

X. No part of any electric line shall be used for the transmission of more than 300,000 watts, except with the consent in writing of the Board of Trade, and efficient means shall be provided to prevent this limit being at any time exceeded*.

XI. All electrical conductors fixed upon the carriages in connection with the trolley wheel shall be formed of flexible cables protected by indiarubber insulation of the highest quality, and additionally protected wherever they are adjacent to any metal so as to avoid risk of the metal becoming charged.

XII. The trolley standard of every double-decked carriage shall be electrically connected to the wheels of the carriage in such manner as either to prevent the possibility of this standard becoming electrically charged from any defect in the electrical conductors contained within it or give a continuous warning signal to the driver or conductor. No passenger shall be allowed to travel on the roof of a carriage as long as there is risk of electric shock.

XIII. An emergency cut-off switch shall be provided and fixed so as to be conveniently reached by the driver in case of any failure of action of the controller switch.

XIV. If and whenever telegraph or telephone wires, unprotected with a permanent insulated covering, cross above, or are liable to fall upon, or to be blown on to, the overhead conductors of the tramways, efficient guard wires shall be erected and maintained at all such places.

XV. Where any accident by explosion or fire, or any other accident of such kind as to have caused or to be likely to have caused loss of life or personal injury, has occurred in connection with the electric working of the tramways, immediate notice thereof shall be given to the Board of Trade.

Penalty.

NOTE.—The Corporation of Newcastle-upon-Tyne or any company or person using electrical power on the tramways contrary to any of the above regulations is, for every such offence, subject to a penalty not exceeding £10, and also, in the case of a continuing offence, to a further penalty not exceeding £5 for every day during which such offence continues after conviction thereof.

Byelaws.

I. The entrance to and exit from the carriages shall be by the hindermost or conductor's platform except at a terminus when the carriages are stationary.

* This regulation has since been cancelled.

II. The carriages shall be brought to a standstill whenever it is necessary to avoid impending danger, and immediately before reaching the following points: (*here follows a list of the stopping places*).

III. A printed copy of these regulations and byelaws shall be kept in a conspicuous position inside of each carriage in use on the tramways.

Penalty.

NOTE.—Any person offending against or committing a breach of any of these byelaws is liable to a penalty not exceeding forty shillings.

Home Office. Coal Mines Regulation Act, 1887. Excerpts from the Special Rules for the installation and use of Electricity, 1905. (Reprinted 1907.)

6. The insulation of every complete circuit other than telephone or signal wires used for the supply of energy, including all machinery, apparatus, and devices forming part of or in connection with such circuit, shall be so maintained that the leakage current shall, so far as is reasonably practicable, not exceed $\frac{1}{1000}$ of the maximum supply current, and suitable means shall be provided for the immediate localisation of leakage.

7. In every completely insulated circuit, earth or fault detectors shall be kept connected up in every generating and transforming station, to shew immediately any defect in the insulation of the system. The readings of these instruments shall be recorded daily in a book kept at the generating or transforming station or switch-house.

42. Electric haulage by locomotives by the trolley wire system is not permissible in any place or part of a mine where General Rule No. 8* of the Coal Mines Regulation Act, 1887, applies. On this system no pressure exceeding the limits of medium pressure may be employed†.

43. In underground roads the trolley wires must be placed so that they are at least 7 ft. above the level of the road or track, or elsewhere, if sufficiently guarded, or the pressure must be cut off from the wires

* Rule 8.—No lamp or light other than a locked safety lamp shall be allowed or used (*a*) in any place in a mine in which there is likely to be any such quantity of inflammable gas as to render the use of naked lights dangerous; or (*b*) in any working approaching near a place in which there is likely to be an accumulation of inflammable gas. And when it is necessary to work the coal in any part of a ventilating district with safety lamps, it shall not be allowable to work the coal with naked lights in another part of the same ventilating district situated between the place where such lamps are being used and the return air-way.

† 250—650 volts.

during such hours as the roads are used for travelling on foot in places where trolley wires are fixed. The hours during which travelling on foot is permitted shall be clearly indicated by notices and signals placed in a conspicuous position at the ends of the roads. At other times no one other than a duly authorised person shall be permitted to travel on foot along the road.

On this system either insulated returns or uninsulated metallic returns of low resistance may be employed.

44. In order to prevent any other part of the system being earthed (except when the concentric system with earthed outer conductor is used) the current supplied for use on the trolley wires with an uninsulated return shall be generated by a separate machine, and shall not be taken from or be in connection with electric lines otherwise completely insulated from earth.

45. If storage battery locomotives are used in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the rules applying to motors in such places shall also be deemed to apply to the boxes containing the cells.

There are other Regulations dealing with Stationary Motors, Generating Stations, Cables, Switches, Fuses, etc. which are set forth in the Special Rules issued by the Home Office.

Railways (Electrical Power) Act, 1903, Cap. 30.

An Act to facilitate the Introduction and Use of Electrical Power on Railways.

Be it enacted by the King's most Excellent Majesty, by and with the advice and consent of the Lords Spiritual and Temporal, and Commons, in this present Parliament assembled, and by the authority of the same, as follows:

1. (1) With the object of facilitating the introduction and use of electrical power on railways the Board of Trade may, upon the application of a railway company, make orders for all or any of the following purposes, namely:

(a) Authorising a railway company to use electricity in addition to or in substitution for any other motive power, and for any other purpose.

(b) Authorising the company to construct and maintain generating stations or other electrical works on any land belonging to the company.

(c) Authorising agreements between the company and any body corporate or other person for the supply to the company of electrical power or the supply to or use by the company of any electrical plant or equipment.

(d) Sanctioning any modification of any working agreement so far as the modification is agreed to between the parties thereto, and is consequential on the introduction or use of electrical power.

(e) Authorising the company to subscribe to any electrical undertaking which will facilitate the supply of electricity to the company.

(f) Securing the safety of the public.

(g) Authorising the issue of new capital by the company for any of the purposes of this Act.

(h) Any other matters, whether similar to the above or not, which may be considered ancillary to the objects of the order, or expedient for carrying those objects into effect.

(2) An order made by the Board of Trade under this Act shall, on coming into operation, have effect as if enacted by Parliament.

2. (1) An order under this Act may contain provisions authorising the acquisition of land by any railway company for the purpose of constructing generating stations or other electrical works, but if power is given by order to acquire the land otherwise than by agreement, the order shall not come into operation, so far as it gives that power, unless confirmed by Parliament, and the Board of Trade may bring in a Bill for confirming the order.

(2) If while a Bill confirming any such order is pending in either House of Parliament a petition is presented against the order, the Bill, so far as it relates to the order, may be referred to a Select Committee, or, if the two Houses of Parliament think fit so to order, to a Joint Committee of those Houses, and the petitioner shall be allowed to appear and oppose as in the case of Private Bills.

3. (1) Before making an order under this Act the Board of Trade shall be satisfied that the public notice required by rules made under this Act of the application for the order has been given, and shall consider any objections made by the council of any county, any local authority, or other person to the application in accordance with those rules, and give to those by whom the objection is made an opportunity of being heard, and if after consideration the Board decide that the objection should be upheld, the Board shall not make the order or shall modify the order so as to remove the objection.

(2) The Board of Trade may, if they think fit, hold a local inquiry for the purpose of considering any application for an order under this Act, and the Board of Trade Arbitrations, etc. Act, 1874, shall apply to any inquiry so held as if--

(*a*) The inquiry was held on an application made in pursuance of the special Act; and

(*b*) The parties making the application for the order and any person objecting to any such application were parties to the application within the meaning of section three of that Act.

4. (1) The Board of Trade may (with the concurrence of the Treasury as to number and remuneration) appoint or employ such persons as appear to them to be required for carrying this Act into effect, and the remuneration of such persons, and any other expenses of the Board of Trade under this Act, shall be defrayed out of moneys provided by Parliament.

(2) There shall be charged in respect of proceedings under this Act before the Board of Trade such fees as may be fixed by the Treasury on the recommendation of the Board of Trade.

5. The Board of Trade may make such rules as they think necessary for regulating the notices and advertisements to be given of any application for an order under this Act or otherwise for the purposes of this Act, and any other matter which they think expedient to regulate by rule for the purpose of carrying this Act into effect.

6. (1) In this Act the expression "railway company" includes a company or person working a railway under lease or otherwise.

(2) Nothing in this Act shall affect any powers which a railway company may have independently of this Act.

(3) This Act may be cited as the Railways (Electrical Power) Act, 1903.

(4) This Act shall come into operation on the first day of January, nineteen hundred and four.

Regulations* prescribed by the Board of Trade under the provisions of section of the

Railway Act, 190 , for regulating the employment of insulated returns, or of uninsulated metallic returns of low resistance; for preventing fusion or injurious electrolytic action of or on gas or water-pipes or other metallic pipes, structures, or substances; and for minimising as far as is reasonably practicable injurious interference with the electric wires, lines, and apparatus of parties other than the Company, and the currents therein, whether such lines do or do not use the earth as a return.

Definitions.

In the following regulations—

The expression "energy" means electrical energy.

The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy.

The expression "motor" means any electric motor carried on a train and used for the conversion of energy.

The expression "pipe" means any gas or water-pipe or other metallic pipe, structure, or substance.

The expression "the Company" has the same meaning or meanings as in the
Railway Act, 190 .

Regulations.

1. Any machine used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.

2. One of the two conductors used for transmitting energy from the generator to the motors shall be in every case insulated from earth by means of insulators of a strong and durable material so shaped as to offer great resistance to surface leakage, and is hereinafter referred to as the "line"; the other may be similarly insulated throughout, or may be uninsulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

* These Regulations must be regarded more in the light of Recommendations in the case of Tube Railways employing an insulated return.

3. Where any rails on which trains run or any conductors laid within the metal-lined tunnels in which the railway is constructed form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated.

4. When any uninsulated conductor forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected to the iron or other metal plates forming the lining of the tunnels unless this lining is otherwise connected to the rails. In each case the connection shall be made through a suitable current indicator.

6. The iron or other metal plates forming the lining of the tunnels shall be so made and connected together as to form a continuous metal tube.

7. Where any pipe is brought into the tunnel from outside, except any pipe belonging to the Company which is not in metallic connection with or laid within six feet of any other pipe, means shall be provided to secure that no portion of the pipe outside the metal tube shall be in metallic connection with the tube or with any conductor of electricity within the tube.

8. When the rails form any part of the return they shall either be electrically connected, at intervals not exceeding 100 yards, to the metal tube by metallic conductors which will not be appreciably heated by a current of 100 amperes, or they shall not be in any metallic connection with the metal tube except by means of the connections to the negative terminal of the generator. In the latter case the rails shall be supported by sleepers of wood, and they shall be of such sectional area and so connected at joints and from one line of rails to another, and where necessary to supplementary conductors or feeders, that the difference of potential between the rails and the metal tube shall not in any part and under any working conditions exceed 10 volts. A test shall be made at least once in each month.

9. When the return is partly or entirely uninsulated a daily record shall be kept by the Company of the difference of potential during the working of the railway between any two points of the uninsulated return at the time when the load is greatest. If at any time such difference of potential exceeds the limit of seven volts, the Company shall take immediate steps to reduce it below that limit.

10. Every line and every insulated return shall be constructed in sections, and means shall be provided at or near each station for breaking the connection between sections.

11. The leakage current shall be tested daily before and after the hours of running with the working pressure and duly recorded. Should the amount of this at any time appear to indicate a fault of insulation, steps shall at once be taken to localise and remove it.

12. The Company shall, so far as may be applicable to their system of working, keep records as specified below. These records shall be preserved for a period of twelve months, and shall, if and when required, be forwarded for the information of the Board of Trade.

Daily Records.

No. of trains running.

Maximum working current.

Maximum working pressure.

Maximum current from the rails to generator.

Maximum current from the metal tube to generator.

Leakage current (*vide* Regulation 12).

Fall of potential in return (*vide* Regulation 9).

Monthly Records.

Maximum difference of potential between rails and metal tube (*vide* Regulation 8).

Insulation resistance of conductors laid outside metal tube (*vide* Regulation 11).

Occasional Records.

Localisation and removal of leakage, stating time occupied.

Particulars of any abnormal occurrence affecting the electric working of the railway.

NOTE.—These regulations only apply to railways constructed underground in metal-lined tunnels.

BOARD OF TRADE. MAY, 1904.

Requirements of the Board of Trade in regard to the precautions to be taken against the risk of Accident by Fire on Underground Electric Railways.

A.

Stations and Permanent Way.

1. Sleepers to be of hard wood, not creosoted, and to be laid in concrete or ballast, and covered with a layer of gravel or finely broken stone free from dust, the ballast to be finished to a level surface so as to form a convenient roadway for passengers in case of emergency. If ballast is not used, the space between the rails to be covered with granolithic slabs, or slabs of a similar material, to form as wide a roadway as possible for passengers. No timber planks to be used.

2. Tunnels to be provided with lights capable of being turned on from the stations at either end of each section and, if necessary, at some intermediate points. The lighting circuits to be independent of the traction supply.

3. Separate entrances to and exits from each platform of the stations to be provided, and to be situated as nearly as possible in the middle of the platforms.

4. All stairways, passages, and exits from the stations to be conspicuously lighted. Not less than 25 per cent. of the lights in these places to be supplied from independent source. If necessary, the exits to be made more conspicuous by the use of coloured lights in addition to white lights.

5. Platforms not to be made of wood, and woodwork to be eliminated as far as possible from signal boxes, lifts, offices, etc., below ground.

6. Efficient hydrants, hose, and fire prevention appliances to be provided.

7. Ventilating ways to be provided wherever possible from the station and the tunnels to the surface.

B.

Equipment.

8. Cars to be constructed of metal; woodwork to be reduced to a minimum and to be non-inflammable. Hard wood to be used in preference to soft. Interior fittings, panels, seats, etc., to be of incombustible material.

9. No main electric cable to be carried through the train, and motors to be placed on the front and rear carriages only. No motor to be situated in the middle of the train.

10. Means to be provided at both ends of every train to enable passengers to alight from the cars in case of emergency. Oil lamps to be carried in every train.

11. Indiarubber or other inflammable insulating materials to be avoided as much as possible, and the outer covering of cables to be uninflammable material that will not give off smoke.

12. Means to be provided for enabling a driver at any part of the tunnel to put himself into telephonic communication with the adjacent stations.

Promotion and Construction. A Railway requires a special Act of Parliament before it can be constructed and worked, but this is not necessarily the case with Tramways or Light Railways. Parliamentary powers obtainable previously to 1870 were embodied in the Tramways Act, 1870. This Act provides for the granting of a Provisional Order which must be confirmed by Parliament, and which authorises the construction of a Tramway. On the other hand, a Special Act of Parliament may be obtained without having recourse to the Tramways Act of 1870.

Under the 1870 Tramway Act the Local Authority of the District may have recourse to the compulsory purchase clause which allows them after the expiration of a term of years or in other specified circumstances to purchase the undertaking. When a special Act is obtained better terms may be given to owners with regard to compulsory purchase. The Act of 1870 gives to the Local Authority the right of veto, inasmuch as their approval must first be obtained. Moreover the Act imposes certain obligations with regard to the Roadway since that portion which lies between the Rails and eighteen inches beyond on either side must be kept in repair by the owners. Since the Tramway Act of 1870 was drawn up almost solely with regard

to horse traction, a provision exists which is obviously unfair to electric traction. It can hardly be said that an electric car wears away more of the roadway than the metal rails. Further than this the opinion has been upheld that owners of electric Tramways must study public safety to the extent of spreading sand on that portion of the road over which they have powers if it is slippery, and maintaining the level between the roadway and the granite blocks which are laid on either side of the rails. Another section of the Act of 1870 allows that on the objection of one-third of the frontagers on that part of the road, no rail may be laid so that thirty feet of it is at a less distance than nine feet six inches from the curb. It may be said that promoters generally prefer to apply for a special Act rather than a Provisional Order.

The Light Railway Act, 1896. The Commissioners for Great Britain to whom application to construct a Tramway or Light Railway must be made, act under authority of the Board of Trade who issue Rules with regard to procedure as in the case of a special Act or a provisional order. This Act involves no purchase powers and under it Local Authorities have no power of veto, but the promoters must consult the Local Authority and the owners of property which it is proposed to take. Under this Act undertakings have been authorised which consist of lines wholly or in part on public roads, but the Act does not define what is meant by a "Light Railway." Applications for lines have been refused by the Commissioners if they consider them pure Tramway schemes. Without applying to Parliament this Act gives compulsory power to take the necessary land, and it cheapens the procedure. It also enables Local Authorities to make advances to Light Railway Companies either by way of loan or by part of share capital. It frees the undertaking from certain onerous regulations of the Board of Trade.

The following documents might be consulted:

I. Tramways and Light Railways.

(1) Board of Trade Rules with respect to provisional orders and other matters under the Tramways Act, 1870 (33 and 34 Vict. c. 78), with a copy of a portion of the Act.

(2) Rules made by the Board of Trade in September, 1896, and modified in October, 1898, with respect to applications to the Light Railway Commissioners under the Light Railways Act, 1896.

(3) Rules dated May 27, 1898, made by the Board of Trade, with the concurrence of the Lord Chancellor, pursuant to the 13th section of the Light Railways Act, 1896.

(4) The Light Railways (costs) (Scotland) Rules, 1898. Dated October 29, 1898, and made by the Board of Trade with the concurrence of the Lord President of Court of Session, pursuant to sections 13 (2) and 26 (4) of the Light Railways Act, 1896.

(5) Additional Rule, dated December, 1903, made by the Board of Trade with respect to the allowance of expenses under section 16 (1) of the Light Railways Act, 1896.

(6) Additional Rule dated May, 1904, made by the Board of Trade with respect to the notices to be given and deposits made in cases where alterations of work are proposed during progress of application. Light Railways.

(7) Requirements, in cases of Application to the Board of Trade, for their approval of the Plan and Statement relating to the Rail and substructure of a Tramway or Light Railway.

(8) Procedure under the Railway Companies' Powers Act, 1864 (as extended by the 38th section of the Regulation of Railways Act, 1868), and the Railways (Powers and Construction) Act, 1870.

(9) Form of Certificate and general Rules scheduled to the Railways Construction Facilities Act, 1864, and an additional Rule made by the Board of Trade under the said Act.

(10) Opening of Tramways or Light Railways on public Roads. Documents to be furnished prior to inspection.

(11) *The Light Railways Act*, 1896, *with Notes*, etc., by Evans Austin, M.A., LL.D., Barrister-at-Law, London, Reeves and Turner.

(12) *The Law relating to Electric Lighting, Traction and Power*, J. Shiress Will, K.C., Butterworth and Co. 25*s*.

II. Railways.

Rules, dated February, 1904, made by the Board of Trade with respect to applications under the Railways (Electrical Power) Act, 1903.

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